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ROLE OF SPACE RESERVATIONS IN CONFIGURABLE PRODUCT DESIGN

Master of Science Thesis

Examiner: prof. Tero Juuti

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ABSTRACT

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Managing product variety and inner variance when trying to fulfill different customer requirements can be challenging in modern market. One key strategy for achieving this goal is mass customizing. Mass customizing can be achieved by way of modularization which has become a trend within the industry during last decades. By conducting modular product development project Konecranes is aiming to sharpen its product management, reduce its inner variance while still satisfying varying customer requirements.

One important part of modular product design and project design processes is space reservations for modules. Understanding their role and taking it into consideration in the product development project facilitates creating working configurations in the delivery process. So far this has not been a systematic process in Konecranes, but it has relied on common sense of the designers.

This thesis reviews concepts of configurable and modular products, and introduces methods to perform modular product development project based on existing product. Based on literature review about the role of space reservation and different space reservation models current situation in Konecranes is analyzed and actions proposed to take this into consideration in the modular product design project and design processes.

As a result of this thesis, a way to model space requirements for the case product is introduced. Also delivery project time design process was revised and a suggestion of new design process is made to pay respect to space reservation mind set.

TIIVISTELMÄ

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Tuotevariaatioiden ja sisäisen varianssin hallinta nähdään haastavaksi nykyajan markkinoilla pyrittäessä täyttämään asiakkaan vaatimuksia. Eräs varteenotettava strategia tähän on massaräätälöinti. Massaräätälöinti voidaan toteuttaa modulaarisuuden avulla, mikä onkin ollut trendinä teollisuudessa viime vuosikymmeninä. Läpikäymällä modulaarisen tuotteen kehitysprojektin Konecranes pyrkii selkeyttämään tuotehallintaansa, vähentämään sisäistä varianssiaan samalla tyydyttäen erilaiset asiakastarpeet.

Yksi erittäin tärkeä osa modulaarisen tuotteen suunnittelua sekä toimitusprosessin aikaista suunnitteluprosessia on moduulien tilavaraukset. Niiden roolien ymmärtäminen ja huomioon ottaminen tuotekehitysprojektissa helpottaa toimivien konfiguraatioiden luomista toimitusprojektissa. Tämä ei ole tähän asti ollut systemaattinen prosessi Konecranesilla, vaan tilavarausajattelu on jäänyt yksittäisten suunnittelijoiden oman näkemyksen varaan.

Tämä teos kertaa konfiguroitavan ja modulaarisen tuotteen käsitteet sekä esittelee menetelmiä modulaarisen tuotteen kehittämiseksi olemassa olevan tuotteen pohjalta. Tilavarausten rooleista ja tilavarausmalleista tehdyn kirjallisuustutkimuksen ja nykytilan analyysin pohjalta ehdotetaan toimenpiteitä tilavarausajattelun huomioonottamiseksi modulaarisessa tuotekehitysprojektissa sekä suunnitteluprosessissa.

Tämän työn tuloksena esitellään case-tuotteelle sopiva tilavarausmallinnustapa. Myös toimitusprojektin aikainen suunnitteluprosessi tarkistettiin ja esitettiin ehdotus uudesta suunnitteluprosessista, joka ottaa huomioon tilavarausajattelun.

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Olli Engbom

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ABBREVIATIONS

BfP	Brownfield Process, method for modular product development based on existing product
CPM	Change Prediction Method, a systematic way of predicting changes in engineering design
CSL	Company Strategic Landscape defines the relation between internal structure of the product and delivery process
CTO	Configure-to-order, a product is configured from pre-designed modules or options
DFX	Design for X or Design for Excellence, where X represents different aspects, e.g. manufacturability, cost, assembly etc.
DSM	Design Structure Matrix, an interaction and impact modelling method.
ETO	Engineer-to-order, a product is defined and designed after the order
MFD	Modular Function Deployment, a systematic method for developing modular product families
MIM	Module Indication Matrix, a tool for finding module candidates by exploring relations between module drivers and sub-functions
PFMP	Product Family Master Plan, a method for visualizing how customer, engineering and components are linked together
PSBP	Product Structure Blue Print, a graphical way of dividing product to generic elements and more detailed solutions
QFD	Quality Function Deployment, a method to convert customer requirements into engineering characteristics

1. INTRODUCTION

Many companies are struggling with expanding product variety due to differing customer requirements they have to fulfill. This expanding product variety creates inner variance and difficulties in product management which can, and usually will, lead to higher cost due to extensive need for redesign, longer lead times, quality problems and poorer lifetime maintainability. These effects are in great disharmony with modern world strategies and goals in the industry, where Lean ideas, cost cutting and shortening delivery times are major drivers for the development.

These product management problems are arising from one-of-a-kind engineered-to-order (ETO) products. After some years, especially if product volumes rises, the product portfolio will grow too big and complicated. For the last decades it has been a trend among many ETO product manufacturers to swift towards the idea of mass customization and configure-to-order (CTO) processes. CTO process can offer same variability to satisfy customer requirements as ETO processes, but with better product manageability, shorter lead times and smaller cost.

One of the most successful ways to create CTO products is modularization of current product and product portfolio. There are numerous studies and works about the development of modular products from the start. These can be called greenfield projects. However in most cases companies going through this transition from ETO to CTO processes have already existing product portfolio customers are satisfied with. Modularizing current product portfolio is often regarded much more viable option to achieve desired goals. These modular product development projects can be called brownfield projects and are not so well covered within literature.

To simplify its product portfolio variance, Konecranes decided to conduct modular product design project for one of its current products. Author of this thesis is a member of this project team. Parallel to every day product development, significance and roles of space reservation modelling was studied to find inputs for new way of thinking, and to create necessary design process steps for applying this scheme of things to every day design work.

2. RESEARCH DESCRIPTION

This chapter describes the research in more detail. It presents research objective and questions arising from the research problem. Research methods and an outline of this thesis is also introduced in this chapter.

2.1 Research objective

Space reservation modelling and its role in product development project and delivery project design processes are not widely covered in the literature. This is also the case within Konecranes. Therefore the objective of this research is to gather information from literature describing different space reservation methods and their role in product design as they can be considered a crucial part of modularization projects.

Simultaneously with the literature study, same topics are inspected from everyday design and product development point of view. This will generate understanding about the current situation in the company and helps analyzing what methods from the literature could be applied.

Konecranes has significant role in this thesis as the main outcome of this thesis is to select the best space reservation modelling method for the use of an ongoing modular product development project. This study is also guiding and giving understanding about the role of space reservation thinking that should be taken into consideration during the product development project. Space reservation step is part of the Brownfield process which the development project is following. The selected method can be used within the company as well as around the industry in similar development projects in future.

It is very important that these objectives are not only studied but also implemented for the existing design process. Design process used in product delivery projects is not taking a stand on space reservation issues at the moment. If space requirements are considered during the modular product development, better configurability of product can be guaranteed during the delivery project. Assuring working configurability will still need space reservation thinking in the design process during the delivery project. Therefore based on the Brownfield Process and study of space reservation modelling, this thesis will suggest steps to be added to existing design process used in Konecranes.

Based on these research objectives, the thesis answers to the following questions:

- What is the role of space reservation in configurable product design?
- How space reservations should be taken into account in this ongoing product development project?
- What kind of different space reservation methods exist?
- What is the most suitable method for this ongoing product development project?

First and third research questions aims to improve knowledge about space reservation modelling from an academic point of view. Second and fourth question’s main contribution is aid in the selection of the best applicable method for the current needs of the company and give design rules for it.

2.2 Research methods

This thesis is a part of a larger modular product design project which aims at creating modular product platform based on existing product. This study is based on literature review on existing modular design processes methods and space reservation methods. Current status within the company is evaluated based on interviews with chief designers, product managers and technology directors. The findings are then analyzed and broader interview, this time also including R&D, sales, manufacturing and other organizations, is carried out which then gives the basis for suggesting suitable methods to be used in this design process. Verification of the results based on suggested actions has been left outside of this thesis as the project is not at such stage that proper evaluation and verification could be established.

In the scientific sense, the research method used in this thesis can be regarded as action research. Normal case studies are conducted by outside researchers. In action research method the researcher participates the studied case and evaluates the results of this participation. However full scale of action research is not shown in this thesis as suggested actions are not yet performed in practice and therefore cannot be evaluated at this stage.

2.3 Thesis outline

This thesis begins with a literature review on the theoretical background in chapter three. The concept of configurable product family is discussed as well as design and sales-delivery processes related to it. From the concept of configurability the thesis continues towards modularity, presenting different definitions of a module and modularity. Five steps of module system are also presented in this stage. Definitions and roles of interfaces are studied. The chapter ends to quick overview of modular design process called the Modular Function Deployment and more thorough look on the Brownfield Process.

The fourth chapter concentrates in literature review around the topic of space reservations. General role of space reservations is observed and discussed. Two different space reservation models, the MAN approach and stop zone methods are introduced.

The fifth chapter focuses on the same things and ideas as the previous one, but this time the space reservations are discussed from Konecranes modular product development process point of a view. Role of space reservation thinking during the design process is commented, most suitable model is selected and the whole topics significance to the development process is analyzed.

3. THEORETICAL BACKGROUND

This chapter introduces theoretical background for the thesis. One of the first goals of this case study development project was to create more configurable modular product structure. Therefore different views of modular design process are presented to emphasize the numerous ways to approach this topic of modularization. From all different methods, one called Brownfield process is used in this product development project and therefore it deserves to be examined closer.

3.1 Configuration in product family

Configuration can refer to design like activity which can be called configuring or configuration task. A configuration can also mean an individual product structure and its configuration (Pulkkinen 2007 p. 69). Pulkkinen discusses more detailed about definitions for these two uses, but instead of certain definition in thesis configuration is studied more for the use of the ongoing project on the background.

3.1.1 Configurable product

In the far ends of manufacturing paradigms are mass production and one of a kind production. Mass customization is a way of working where benefits of these both paradigms are aimed to achieve – combining pre-defined and pre-designed elements to fulfill customer needs as accurately as possible. This gives high requirements to product design and production readiness to achieve goals aimed for. Configurability can be seen as a part of mass customization where customer requirements are answered with configurable products. (Juuti 2008 p. 33; Jørgensen 2009 p. 2)

There are different definitions for configurable product within academia and industry. Often configurable product is understood in various ways in different organizations within company. According to Tiihonen et al. (1998a p. 1) configurable products have following properties:

- The product has been pre-designed to meet a given range of different customer requirements.
- Each delivered product individual is adapted to the needs of a customer.
- Each product individual is specified as an arrangement of pre-designed components. Thus, there is no need to design new components as a part of the sales-delivery process.
- The product has a pre-designed architecture.

- No creative or innovative design is needed as a part of the sales-delivery process. Rather, a product individual can be specified in a routine manner.

Figure 1 is presenting a configurable product in relation to its price and adaptability to customer requirements. In ideal situation it has the effective cost structure of mass product but from customer point of view it is customer tailored product filling all customer needs.

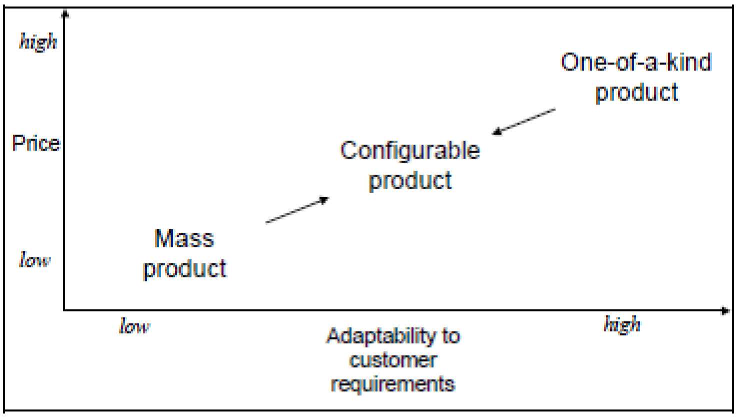

Figure 1. *Configurable product is utilizing benefits of mass product and one-of-a-kind product. (Tiihonen et al. 1998a p. 5)*

In their study Tiihonen and his group (Tiihonen et al. 1998a) interviewed several Finnish companies in order to identify why they produce configurable products. Reasons that came up most often were:

- Ability to fulfil a wide range of customer requirements
- Shorter lead times in the sales-delivery process
- Increased control of production
- Reduction in customer-specific design
- Improved quality
- Easiness of selling
- Less capital tied to work in progress
- Reduction of errors

There are usually two roads to configurable product design. First case, which is also the case in this project the thesis is related to, is that company has been delivering one-of-a-kind engineer-to-order products. As time goes by, number of different deliveries grows and managing product portfolio becomes more difficult because of excessive amount of design and customer specific engineering. In this situation companies are aiming for shorter lead times, shorter design times because of re-use of existing design, improved quality, easiness of selling and reduction of errors as well as more manageable product portfolio. The delivery process itself is quite similar in configurable product as in one-of-a-kind product. (Tiihonen et al. 1998b p. 1; Lehtonen et al. 2003 p. 28)

The other road is to take it from mass products to configurable products. This might occur when customer demand for customized products arises. Customer preferences and habits has changed since Henry Ford once stated: “Any customer can have a car painted any color that he wants so long as it is black”. Keeping in mind the benefits from mass production companies can produce configurable products to satisfy increased customer needs. In these cases there usually is better knowledge within company about product functions customers are requiring than in case of one-of-a-kind products. (Jørgensen 2009 p. 1; Tiihonen et al. 1998a p. 5)

3.1.2 Processes related to configurable products

Configuration is not just sales or design issue. It is a company level mode of operation. There are two main processes related to configurable products: the product development process and the sales-delivery process. The goal is to separate these two tasks. In Figure 2 key concepts related to these two processes are summarized. Aim of the product development process is to design a configuration model which is a systematic documentation of the configurable product making the configuration process possible (Nummela 2006 p. 51). This includes all the components available, rules for combining the components and rules how features derived from customer needs are achieved. This configuration model is then used in the sales-delivery process to produce configurations, which are detailed descriptions of which components each individual product consists of. (Juuti 2008 p. 33; Tiihonen et al. 1998a p. 2)

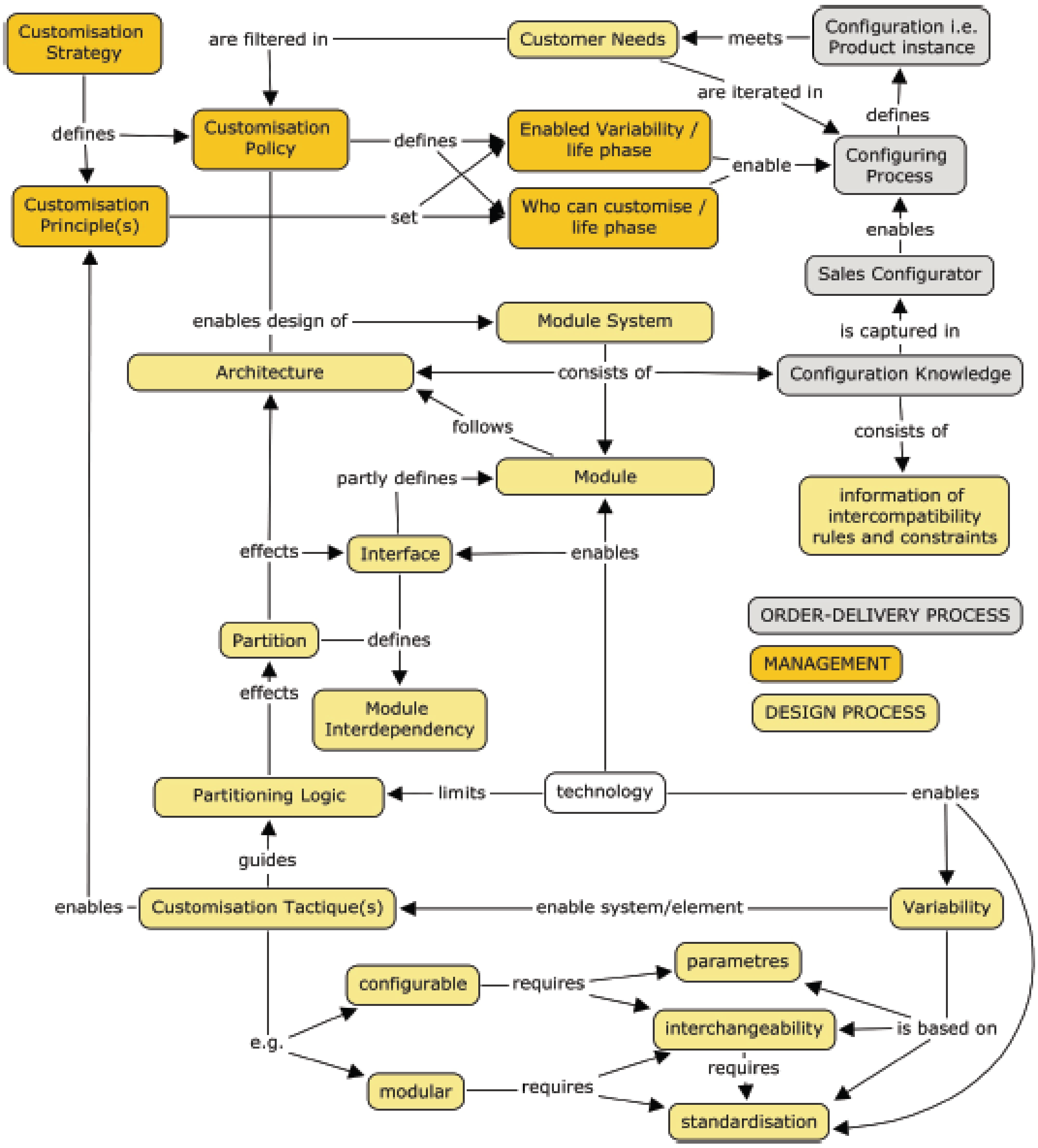

Figure 2. *Separation of sales-delivery and product design processes, key concepts related to them and relations between the concepts. (Juuti 2008 p. 37)*

In one-of-a-kind product sales-delivery process includes the design phase as the product is designed to fulfil customer needs during the process. In case of configurable product, all the modules and components are designed during independent product development project. This resembles the process for fixed product design. The product satisfying customer needs is later configured during sales-delivery process based on pre-defined modules and configurations. (Tiihonen et al. 1998a p. 2)

3.1.2.1 Product development process

In product development process the configuration model of the product is created. The configuration model exhibits available components and modules, rules between their combinations and the way different customer requirements are achieved by combining them. This configuration model can then later be used in sales-delivery process to select right unique design for customer purposes. (Lehtonen et al. 2003 p. 2)

Product architecture is a common structure representing each configuration. The product architecture specifies the elements that are changeable and variable from fixed elements which appear in every configuration. It also defines the relations between different elements. These variants derived from the architecture must be matched to typical combinations coming from the customer needs to be successful from sales perspective. (Pulkkinen & Bongulielmi 2004 p. 3)

Documentation is a critical step of product development process that enables the effective usage of the configuration model in sales-delivery process. This might consist of different configuration models for the same product. These different models are targeted to different groups within organization. For example configuration model for engineers can be specific containing detailed information about which components different configurable elements consists of. Model created for sales personnel can be more robust at defining what configurable elements fulfil different customer needs. (Tiihonen et al. 1998a p. 3)

Often modular project architecture is a requirement for a configurable product, meaning different configurations can be created by predefined modules. According to Tiihonen et al. (1998a) exception to this can be parametric product which is not necessarily modular.

Often it is thought the product should be fully configurable, so that every variant needed could be formed with predefined modules. This is usually true when moving from mass products to configurable products. But in many industry cases where products are one-of-a-kind delivery projects, it is generally not cost-effective to try to cover all requirements with configuration. Some of the most individual requirements can be designed during sales-delivery process. Usually these requirements are cost wisely related only to small portion of the whole product cost. This kind of product is called partially configurable product. (Tiihonen et al. 1998a p. 3)

3.1.2.2 Sales-delivery process

After the configuration model is created and documented in product development process, it can be used in sales-delivery process. Figure 3 shows sales-delivery process of a configurable product. It is initiated by order or request-for-proposal from the customer. During the first step of configuration process customer requirements and preferences to the product are defined. This step will create configuration model 1 in Figure 3. In more complex situations a second configuration model is later engineered if it cannot be formed during sales phase. In second engineering phase technical configuration process is done to transform customer selections to accurate product descriptions. After this phase production and assembly orders can be created. (Jørgensen 2009 p. 6)

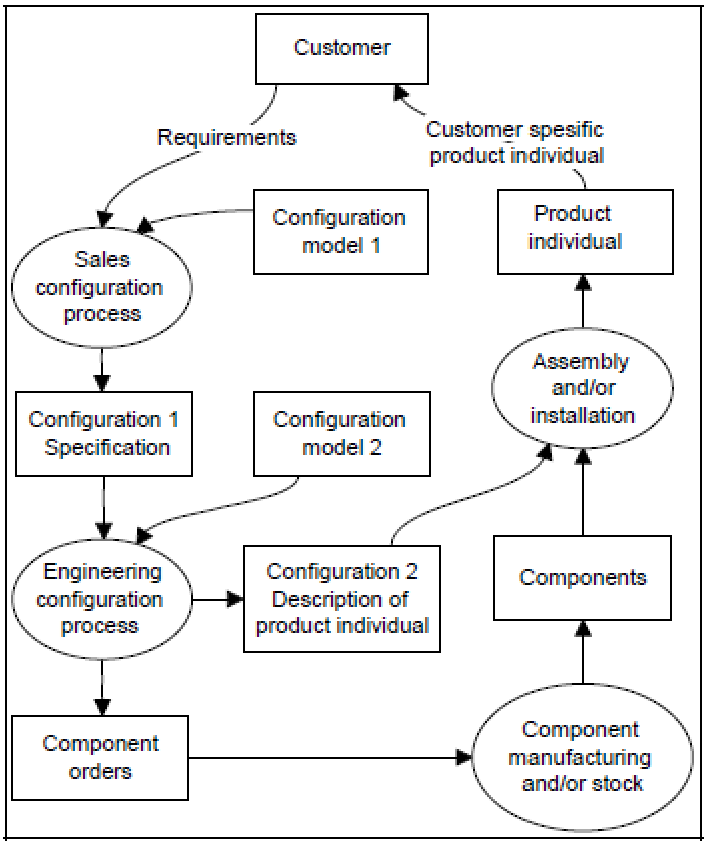

Figure 3. *General sales-delivery process model. (Tiihonen et al. 1998a p. 3)*

These steps mentioned do not have to be done in separate phases but they can be conducted once during sales or engineering stage depending on the company's policies and complexity of the product. If the product is simple enough the configuration can be done during sales phase. There are also some examples where the configuration is done by the customer. This is the case for some online shops where the customer can select components to configure and build computer. (Tiihonen et al. 1998a p. 3-4)

In complex product cases engineers are already needed during sales phase to support the sales organization. This need can be reduced by creating a sales configurator. Sales configurator is a tool that can be used to create the configuration. It should not allow to create any configurations which are not possible to produce. It includes all the rules and relations between different elements and components of the product configuring module. If the configurator is properly created, it enables the configuration of complex products to be done by sales or even by customers. For example customer can go to car manufacturer's web page, select all the features wanted, and the configurator will create the unique product, give exact price and sometimes delivery time without any sales activities needed. (Tiihonen et al. 1998a p. 4)

Tiihonen and his research group studied experiences of configurable products in Finnish industry (Tiihonen et al. 1998a). They noticed that in most cases sales specifications were incomplete or invalid. These deficit specifications created a burden to engineering department whose task it was to fill the incomplete and correct the invalid ones. The later these errors are noticed in the process the bigger the costs are to correct the specifications. According to the study these errors rarely reached the production phase but they had a significant impact on lead times due to iteration in sales-delivery process.

3.2 Modularity

As discussed earlier, configurability in products can be achieved by the ways of modularity. Modularity is quite a vast concept and there are different views what modularity is and how it should be applied. In this thesis, some different definitions for modularity and a module are introduced and the concept of module system is discussed as well as a couple of examples about modular product development methods are presented.

3.2.1 Definitions of modularity and module

The study of modularity has its backgrounds on architecture and building industry. Even the word ‘module’ comes from the ancient Rome where it was used as a measuring unit. In modern ages modularity has been studied for example by famous architect and designer Alvar Aalto. His idea was to create standardized configurable house architecture. (Lehtonen 2007 p. 29)

Probably the most significant study about modularity in the field of manufacturing industry has been done by Karl-Heinz Borowski. In his book *Das Baukastensystem in der Technic* (1961) he presents the rules for modular system model called Baukastensystem. Baukastensystem consists of constructional elements called Baukasten, which then can be further divided into smaller constructional elements called Baustein. Borowski also emphasized that these constructional elements are undivided entities within the system having continuous interfaces. Interchangeability of the components is also considered as a requirement for the system allowing configurability according to Borowski.

There are numerous different definitions for a module and modularity in the literature. Andreasen (2011) defines the term module in the following way:

“*A module is a product entity, which from a function or organ point of view has distinct function and requested properties, but at the same time such interfaces and interactions with other entities that you can see it as a building block in the parts structure*.”

Hölttä’s (2004) definition of module is:

"*A module is a structurally independent building block of larger system with well-defined interfaces.*"

These both definitions are similar to one Lapinleimu (2000) uses:

"*A module is a structural entity of the final product which has carefully defined interfaces."*

Erixon (1998) defines modularization the following way:

"Modularization is decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific reasons."

Lehtonen (2007) is dividing modularity into two different categories: M-modularity, in which "M" refers to Finnish word of configuration, and life-cycle modularity. In M-modularity Lehtonen defines modularity as follows:

"*A block (any assembly of the product or part of the system) is a module if it has an assigned interface and it is a part of a modular system.*"

In this context Lehtonen also defines modular system as follows:

"*A modular system is a system consisting of blocks which involves the interchangeability of the blocks.*"

In his dissertation Lehtonen leaves some forms of modularity outside of the definition of M-modularity. In these cases modularity is related to the life-cycle of the product instead of the configurations. These can be divided into three different categories of life-cycle modularity which are also presented in Figure 4:

- Modularity based on reasons of manufacturing
- Modularity based on reasons of maintenance
- Modularity based on logistical reasons

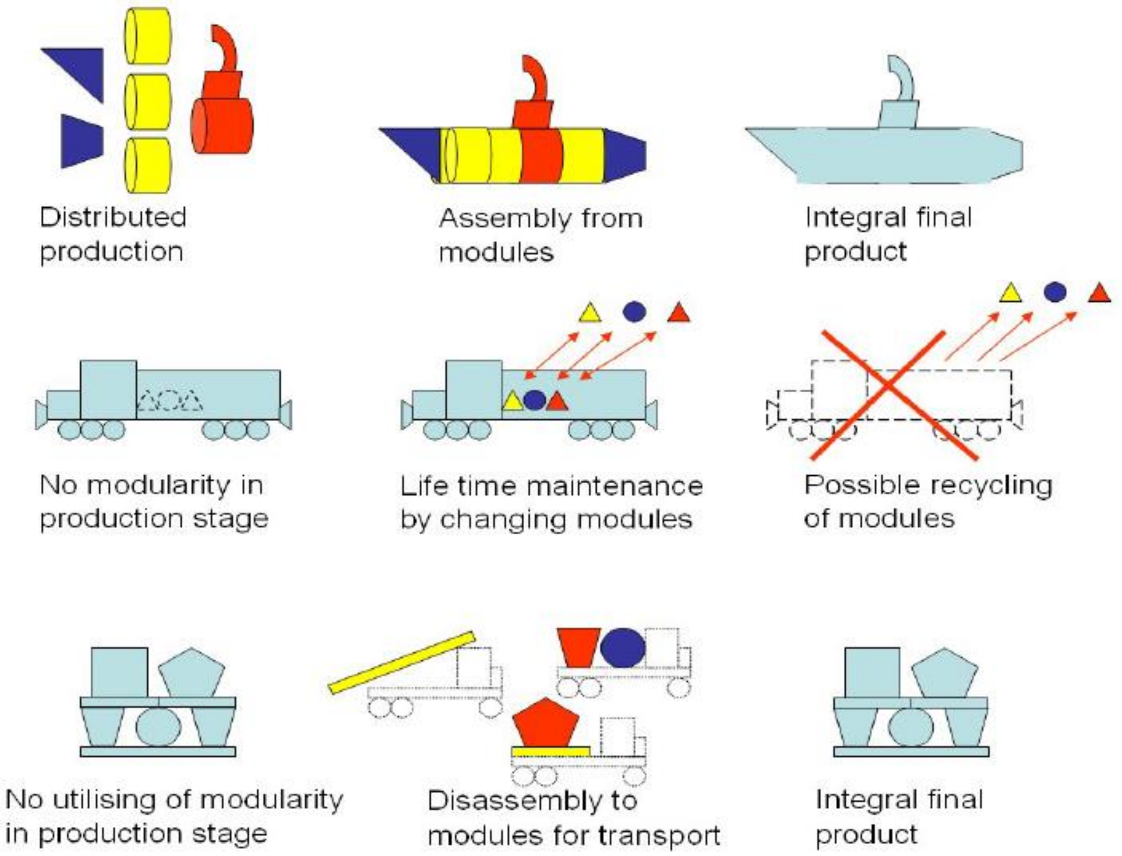

Figure 4. *Three different types of life-cycle modularity based on reasons coming from manufacturing, maintenance and logistics. (Lehtonen 2007 p. 90)*

Example case of assembly modularity is the German submarine manufacturing during WWII. Bottle neck of the production was the basin capacity. To tackle this problem Germans designed their submarines a way that they can be assembled from smaller blocks which were build outside of the basin. When the blocks were ready, they were taken to the basin for connection to form complete submarine. This reduced the assembly time significantly and enabled bigger production numbers. (Lehtonen 2007 p. 25)

Life-cycle modularity is not discussed more thoroughly in this thesis as it is not based on variation in product structure coming from customer requirements. As Lehtonen (2007) states, modular system is not needed and in most cases it does not even exist. However, life-cycle modularity can become M-modularity if some of the modules are designed to be interchangeable because need for variation in the product.

As stated earlier, there are many definitions for module and modularity. However, in all of these a module is defined as a block, which has strictly defined interfaces between other modules and the product. A module is independent and interchangeable unit which has some functionality within it. In this thesis Lehtonen's (2007) definitions are used for a module and modularity.

Lehtonen et al. (2013) presents three main principles, based on Borowski (1961) which a module has to achieve to truly be a module:

1. A module has unbreakable interface, which will not be changed.

This is important as most advantages of modulation comes from dividing complicated products to smaller, less complicated units. These advantages are hard to achieve if the interfaces are not clearly defined or they are constantly varying.

2. A module exists only as a part of a modular system.

No assembly is a module if it does not belong to any modular system where it has a function. Assembly with standardized interface cannot be considered alone as a module in varying product structure if it lacks business oriented logic behind it. Lego blocks are often considered as a modules since they have standardized interfaces between each other – so they could be used anywhere. But in reality if there was no consideration where these blocks were to be used, they could not be called modules.

3. In one module system modules are relatively same size compared to each other and modules are not consisting of other modules.

Assembly of modular product is easy if the configuration is one leveled. This is sometimes difficult when a product has layered structure which should be completed by nested module systems.

Following these three principles, it can be seen that variation in a modular product can be implemented by only five different ways. These five different ways are presented in Figure 5.

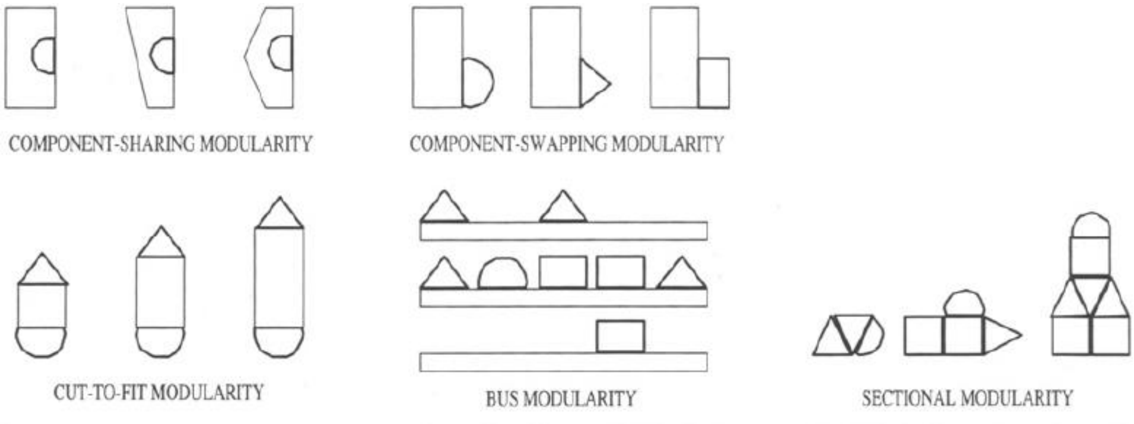

Figure 5. *Five different types of modularity presented by Lehtonen (Lehtonen at al. 2013)*

These five types of modularity were first introduced by William Abernathy and James Utterbeck in the book "Pattern of Industrial Automation", published in 1978. Later there has been some other candidates in addition to this group, but generally those have been ruled out. Two special case are still to be considered, on-off modularity and stack modularity. On-off modularity is an embodiment of component interchangeability, in which component is used or the space reservation made for it is left empty. In stack modularity, subtype of parametrical modularity, parametrical configuration is achieved by multiplying the number of modules.

In his dissertation Juuti (2008) presented a way to model a modular system consisting of five different design elements which can be seen in Figure 6. These are later referred as “the five elements of module system”.

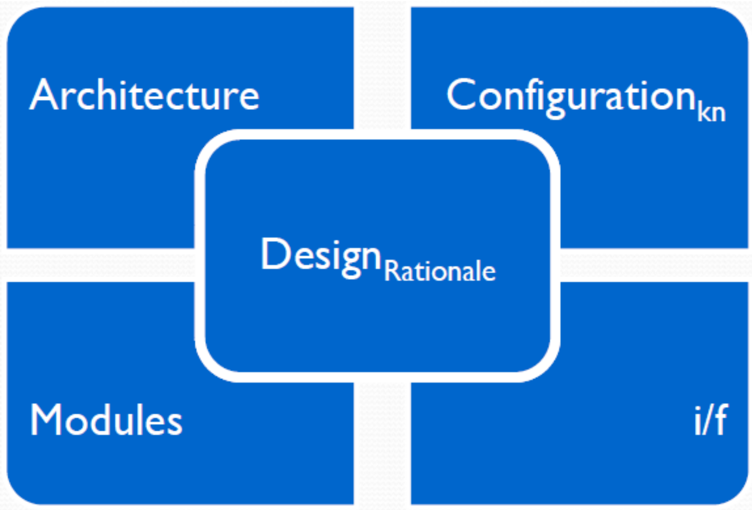

Figure 6. *The five elements of module system – architecture, configuration knowledge, modules, interfaces and design rationale. (Lehtonen et al. 2013)*

Pakkanen et al. (2013) defines these elements the following way:

Design rationale – Partitioning logic reasoning behind certain module division.
Modules – Building blocks of the module system.
Interfaces – Enablers of interdependency and interchangeability of the modules.
Architecture – Layout definition of the module system. Defines location of modules and interfaces.
Configuration knowledge – Compatibility and constraints between modules and customer needs.

According Lehtonen et al. (2013) this method has been successfully used several times analyzing different real life cases across the industry. This list is however not definite, in some cases all the five elements are not needed for successful design. For example in a case of life-cycle modularity of the submarine, discussed earlier in this section, one segment of the submarine can be only in one certain location and thus no configuration knowledge is needed.

3.2.2 Interfaces

Interfaces are one of the key issues when discussing about modularity, modular design and space reservations. Hence different definitions of interface are introduced and its significance to the topic of this thesis is discussed.

3.2.2.1 Definition of interface

When the definitions of module and modularity were presented earlier, it can be seen that the word ‘interface’ can be found from almost all of them. Almost every study about modular designing and modularity emphasizes the importance of interface knowledge and the role of interfaces. However there are not that many studies about the definition and perception of a product interface within engineering design. Parslov & Mortensen (2015) have done thorough study about the definition of term ‘interface’ in academia.

One of the earliest definitions of ‘interface’ comes as far as year 1882 when it was defined the following way (Parslov & Mortensen 2015 p. 4):

“Interface is a face of separation, plane or curved, between two contiguous portions of the same substance”

Since then the definition has evolved and in this thesis it will be viewed more closely from the modular product engineering design perspective. Ulrich (1995) defined the interface to be a certain physical connection:

“By definition, interacting components are connected by some physical interface. Interfaces may involve geometric connections between two components, as with a gear on a shaft, or may involve non-contact interactions, as with the infrared communication link between a remote control and a television set”

His idea was that there has to be a physical interface for interaction to occur. In the case of his definition, IR transmitter on the remote control and IR receiver in the television are forming the physical interface. On the other hand, more recent studies generally regard the interface as a part of a module rather than it being a separate object between two elements. These both viewpoints can be considered right depending on which cases they are used. (Parslov & Mortensen 2015 p. 5)

In their study Parslov & Mortensen (2015) found out 13 different perceptions of interfaces. Sketches of these 13 perceptions of the manifestation of interfaces are shown in Figure 7.

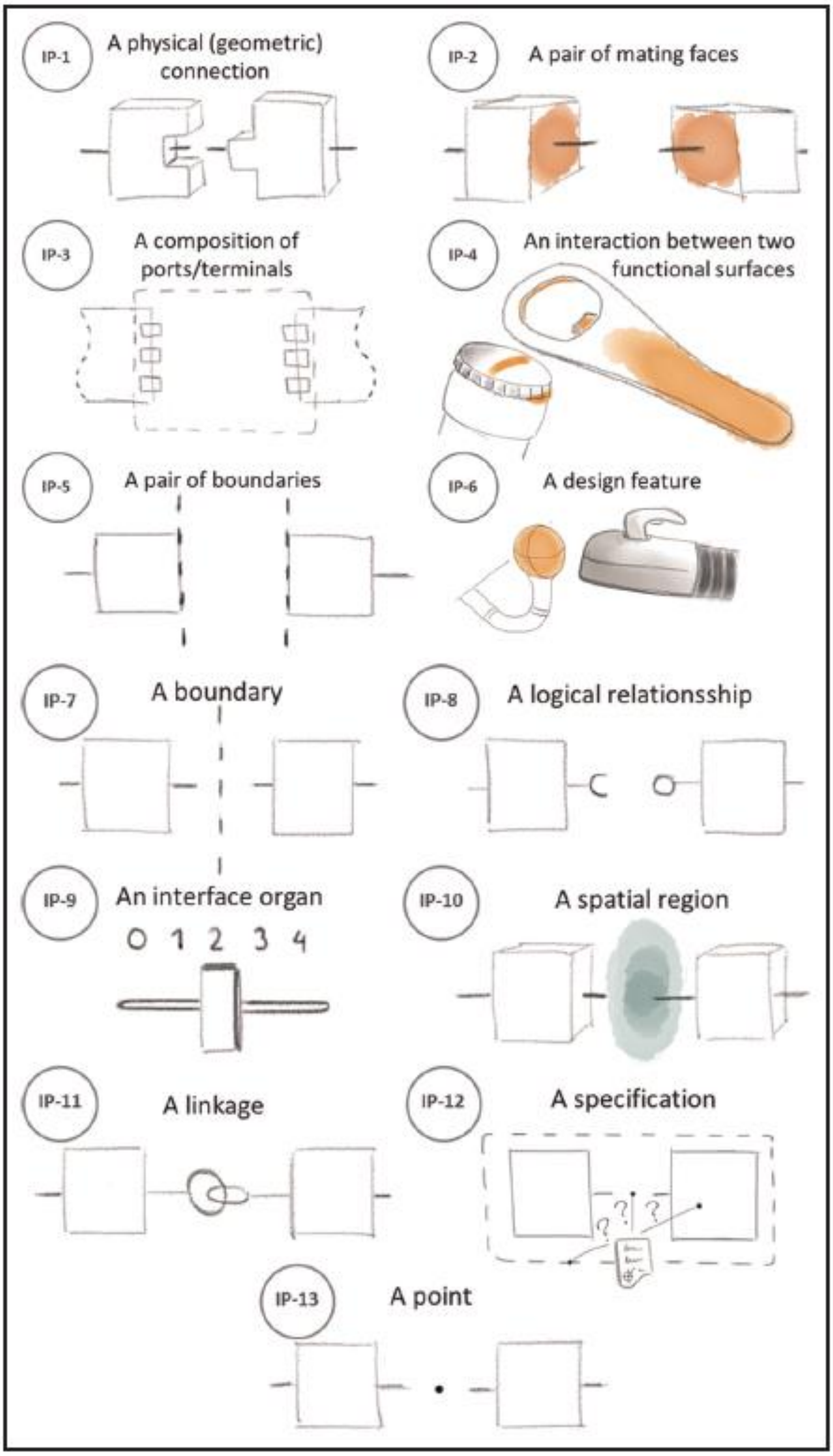

Figure 7. *13 different perceptions of interfaces found in the literature (Parslov & Mortensen 2015 p. 10)*

Generally these 13 different perceptions cannot be seen exactly comparable to each other as some of them are quite metaphorical representations and some are very specific illustrations. Parslov & Mortensen (2015) wanted to point out with their study that the concept of interface is always affected by designers own experience and conceptual and educational backgrounds.

3.2.2.2 Role of the interfaces in modularity

Many authors consider interfaces and their designing the most important aspect of modular designing. Interfaces should be defined at an early stage of the design process to allow parallel design work of the modules to proceed. (Blackenfelt & Sellgren 2000 p. 2) Andersson & Sellgren (2003) suggests focusing on simulation of interfaces while designing modular products as traditionally the influence of the interfaces on the behavior and performance of the module and whole product are not frequently considered.

The requirements for interfaces depends on the reasons behind the whole modularization project. Ulrich (1995) discusses interfaces with terms standardized and well-defined, where Erixon (1998) uses the word specified. Standardized interfaces are used when the idea of modularization arises from creating more variety, where many variant modules should share the same interface. Terms well-defined and specified are not so absolute and clear. Certainly all interfaces should be well-defined and specified, but the general idea behind these words are that the interfaces should be understood by all parties involved without obscurity. (Blackenfelt 2001 p. 36)

The key idea of designing standardized interfaces for modular product architecture is to enable interchangeability and independence of the modules. Interfaces should be designed in a way which enables usage of not only existing modules but modules which are designed later in the life cycle. Schuh et al. (2014) suggests documenting interfaces in three steps: 3D CAD file, drawing defining tolerances and production information and text description. Ownership of the interfaces is also crucial issue as someone should be responsible of the interfaces and their documentation. If this aspect is not taken into consideration, it is highly likely that the modular architecture and its benefits are lost. (Pakkanen 2015 p. 206-207)

3.2.3 Modular design processes

Several different proposals exist for design processes, but most of them concentrates only in developing a single product. The whole idea of variable and configurable product family is not taken into consideration. Companies in the industry have developed their own methods, but due to competition those are kept strictly within the company walls. In this chapter one process is looked closer and few others presented. (Juuti 2008 p. 44)

3.2.3.1 The Modular Function Deployment

One systematic method for developing modularity in product families is called Modular Function Deployment (MFD) which was presented by Erixon (1998). The procedure supports design engineers to create good and robust product structures. It aims to find optimal modular structure that takes in consideration both the customer and company needs. MFD consist of five different steps presented in Figure 8.

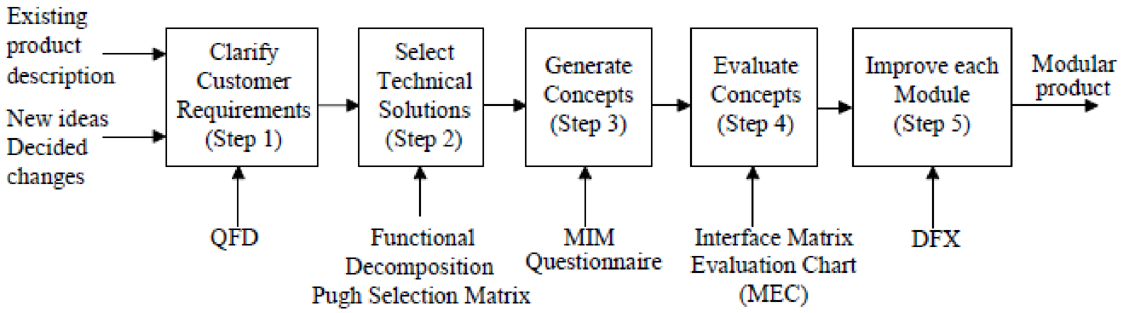

Figure 8. *The Modular Function Deployment, MFD (Erixon 1998 p. 65)*

Even though this process is here presented in a linear straightforward manner, in reality the starting step might vary and almost always some iterative rounds are needed. However, for the successful use of the MFD tool, it is vital to go through all the presented steps to reach a usable solution. For simplicity, the MFD is here presented in its ideal linear manner. (Erixon 1998 p. 65)

The first step of MFD is to clarify the customer requirements and needs. Within this step it is important to segment the markets, recognize the customer needs and apply Quality Function Deployment (QFD) analysis. In this thesis the QFD is not explained more thoroughly, but detailed description of the method can be found from Yoji Akao's writing (Akao 1990). The customer requirements need to be clarified separately on all different segments, as requirements and their importance may vary between different customer segments. Besides the customer market, also companies own needs, including project goals, product strategy and brand imago should be clarified. To clarify and define these, (Ericsson & Erixon 1999) are asking four questions:

- What is the future vision of the product?
- How the product is profiled on the markets?
- Who are the most important customers?
- Who are the toughest rivals?

After finding company goals, the QFD is used to identify important design requirements and it has special emphasis on modularity. QFD-matrix has customer needs on the other axis and product features on the other. Their relation is then marked in a weighted scale from one to nine. By applying this method, the most important features can then be found. After this first step of the MFD, the specification of the product designed must be formed.

The second step of the MFD concentrates on selecting the best technical solutions to achieve requirements defined in the first step. This means breaking down the product into functions and technical solutions creating these functions. This is normally referred as a functional decomposition which stands as a solid base for the creation of good modular product design. To achieve good modular product design, clear independence between different functions must be created. If the functions do not have an effect on each other, they can be easily replaces by other modules without affecting the whole product which is generally a carrying idea of modular product structure. (Erixon 1998 p. 69)

Independencies of the functions are studied with a structured method matrix showing relations between different technical solutions and functions. This method points out the interactions and possible problematic functions which may then be divided to eliminate the interactions. After finding possible technical solutions they are evaluated against the criteria coming from the first step of the MFD process to find the best solution for the product.

In the third step of the MFD, the technical solutions selected in the previous step are compared to modularity drivers deriving from the company's strategy with the help of Module Indication Matrix (MIM).The purpose of MIM is to combine technical solutions and to create possible module indicates. According Erixon (1998) the module-drivers can be divided to six main categories including total of 12 different drivers:

Product development and design

- Carry-over
- Technological evolution / technology push
- Planned design changes / product planning

Variance

- Technical specification
- Styling

Production

- Common unit
- Process and/or organization re-use

Quality

- Separate testing of functions

Purchasing

- Supplier offers black box

After sales

- Service and maintenance
- Upgrading
- Recycling

These are generic drivers which then can be complemented by company specific drivers like strategy, legal restrictions, etc. (Erixon 1998 p. 73)

These drives are then assessed against every sub-function of the product in MIM matrix which can be considered as a heart of the MFD method. As in QFD-matrix, in MIM the relations are weighted on a scale from one to nine. Example of a generic MIM can be seen in Figure 9.

Module driver	Sub-function (techn. solution)	Sub-function 1	Sub-function 2	Sub-function 3	Sub-function 4	Sub-function 5
Company specific						
Development and Design	Carry-over					●
	Technology push			●		
	Product plan					
Variance	Technical spec.				●	
	Styling					
Prod.	Common unit	●			⊘	
	Process/Org.			●	●	
Quality	Separate test	○		⊘		
Purchase	Black-box eng.	⊘				
After sales	Service/maint.	⊘		●		
	Upgrading					
	Recycling				○	

● = Strong driver (9)
⊘ = Medium driver (3)
○ = Some driver (1)

Figure 9. *Generic example of Module Indication Matrix (MIM) (Erixon 1998 p. 78)*

Sub-functions which have either many, or unique, strongly weighted module-drivers, can alone form a module or be a base for one. If some sub-functions are not related, or only slightly related to module-drivers, they can possible be merged to other sub-functions having similar driver relations. The modular structure of the product can be then formed by gathering the most suitable modules from MIM and merging the other sub-functions to modules.

The fourth step of the MFD focuses on evaluating the modular concepts found in step three, visualization and analyzing of the interfaces between the modules. As discussed earlier, interfaces have a vital impact on the final product and creating the variety from different options. For this reason evaluation of interfaces is a first part of this step.

Different types of interfaces between modules are discovered by using interface matrix seen in Figure 10.

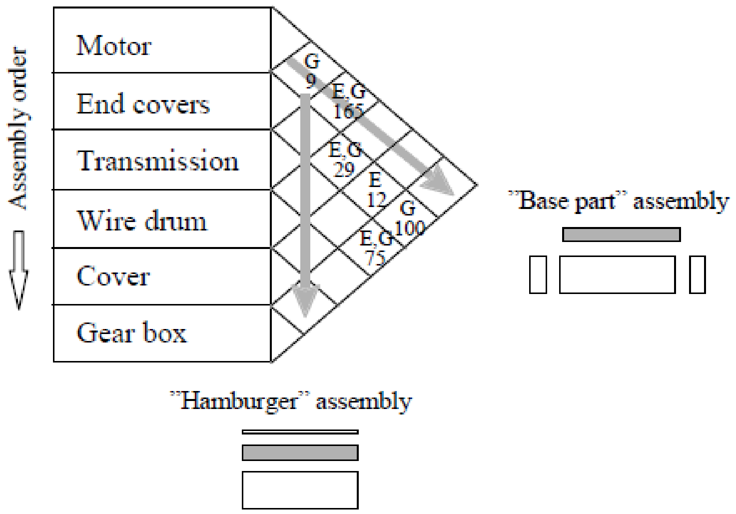

Figure 10. *Interface matrix (Erixon 1998 p. 84)*

Arrows in the matrix represent the desired assembly order. It can either be a "hamburger" assembly meaning all the components are assembled on top of each other. Other way to assemble is to use "base part" assembly principle, where there is one base part to which all the elements are attached. Depending on which assembly method is selected, all the interfaces that are not under arrow representing the selected method should be avoided or eliminated. This mean that in case of "base part" assembly there is interfaces only between the base element and elements assembled to it, but no interfaces between two other elements. (Erixon 1998 p. 84)

Besides evaluating the interfaces, Erixon (1998) proposes other tools for concept evaluation. One of these is the method of ten metrics and/or rules created for different life time phases of the product which can be used to evaluate selected concepts.

The fifth and final step of the MFD includes improving each module and creating documentation for the product. The documentation should be done in a way which enables later understanding how the selected product structure was chosen. Accurate specification for all modules should be done, including all technical information about module itself, interfaces and variants as well as commercial information. MIM and QFD-matrix can be used for this to illustrate for example, that if some module is chosen because of serviceability and maintainability, it should then be designed to easily be replaced and maintained. (Niskala 2014 p.33)

After documentation, the focus in fifth step is in improving all modules independently. For this Erixon (1998) suggests using different DFX methods.

3.2.3.2 Other modular design processes

As stated earlier most of the design processes are not focused on product variability and thus are not in the interests within this thesis. Juuti (2008) mentions models from Kohlhase and Birhofer, which are based on computer-aided optimization methods. This method is quite high level and is not really supporting the development of modular structure. Other method mentioned by Juuti is presented by Lehtonen (2007) which is based on V-model. Idea of this method is to start the design process from value chain analysis. The Brownfield process presented by Pakkanen (2015) is based on this model.

There is a master's thesis about designing process of modular product architecture within Konecranes (Niskala 2014). In this thesis Niskala is introducing Brownfield process and Modular Function Deployment as two potential design processes used within Konecranes. In his thesis Niskala compares these two methods and evaluates their usability within the company. Summary of his comparison can be seen below in Table 1.

Table 1. *Summary from comparison between BfP and MFD, translated from (Niskala 2014 p. 64)*

	Customer orientation	Business environment	Relations between customer needs, product functions and technical solutions	Configuration knowledge	Overal view on the product family	Interface ananlysis and visualization	Easy and illustrative tools	Literature
BfP	+	+	+	+	+	+	-	-
MFD	+	+	+	-	-	+	+	+

The time of his thesis back in 2014, information about the Brownfield process was based on few articles and interviews and this was considered as a drawback for it. Therefore, Niskala chose to use MFD in creation of the designing process of modular product architecture within Konecranes. After 2014 there has been a dissertation about Brownfield process (Pakkanen 2015) which makes its use more tempting and justified. This is one of the reasons the project which this thesis is a part of is executed based on the Brownfield process. Therefore the Brownfield process is reviewed more thoroughly in the next section.

3.3 Brownfield process

Most of the product development processes described in various studies are focused on new product development. Using building industry terms these are often referred as greenfield processes. As the case study project of this thesis is related to develop new product for existing markets with technology already known and in use, these greenfield product development processes are not the best choice for this case.

There are not so many studies about developing modular products which are based on current product offering on existing markets. As a solution for this, a method called the Brownfield Process (BfP) is examined closer. It was first introduced in (Lehtonen et al. 2011b) and then later described more detailed in (Pakkanen 2015).

3.3.1 Overview of the Brownfield Process

The earliest model presented in (Lehtonen et al. 2011b) included five main steps:

1. Defining business targets.
2. Drafting the proposed module architecture using mainly old solutions and components.
3. Updating and rationalizing the market and customer requirements.
4. Creating a modular architecture with minimum amount of variation. Defining the amount of new design required.
5. Documenting the reasoning behind the selected architecture.

The concept of the process has stayed relatively same, but (Pakkanen 2015) presents BfP in smaller and more manageable sections. This evolved version is also the one followed in the study case of this thesis, and therefore it is discussed more thoroughly in this chapter.

The BfP consists of tens steps, all related to at least one of the elements in the Module System discussed in section 3.2.1 These five elements of the Module system are partitioning logic, set of modules, interfaces, architecture and configuration knowledge. The ten steps of BfP and their relations to the Module system are illustrated in Figure 11.

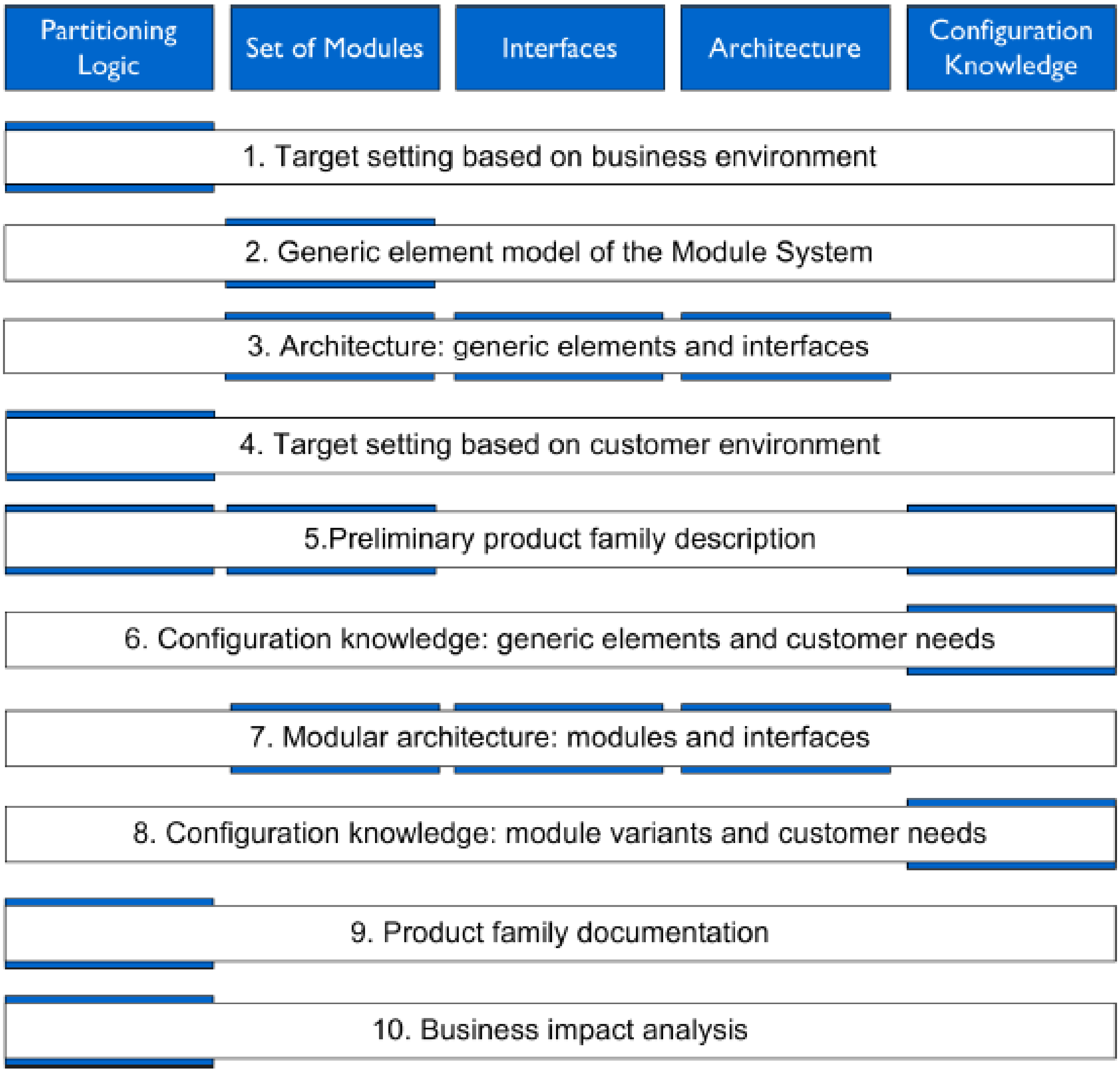

Figure 11. *The Brownfield Process (Pakkanen. 2015 p. 172)*

Reason for product development projects are usually increasing competitiveness and profitability of the product. This is also the reason why the BfP starts and ends with business related tasks to make sure the process has truly business related goals and to study what effects the process has for business point of view. Design aspect of the BfP focuses on modular architecture and configuration knowledge which are useful promoting re-use in the sales-delivery process.

3.3.2 Usage of the Brownfield Process

It is very common that during the course of time number of different product variants grow due to new feature designs. These variants derives often from customer requirements of new features but also designing those to compete in markets. After some time this constant evolution creates multiple variants which are causing confusion in the product management as well as in sales-delivery process. Product itself might become un-suited for the business or customer requirements.

According to Pakkanen (2015) the BfP is made for these situations. Its purpose is not to design totally new design but use the potential re-designing with the already proven solutions. Aim is to re-design existing product variants to more modular product family. Based on findings of current product assortment this method strives to form a common architecture on which different variants can be built on.

Every step of the BfP includes approaches and tools aiming to achieve outputs which are described later when each step is examined closer. None of the tools or approaches used are new, but Pakkanen is suggesting using of existing well known design methods, tools and approaches when applicable. Some of the tools have been modified for better suitability and some new support has been designed.

3.3.3 The Brownfield Process steps

As presented in Figure 11 the BfP consists of ten different steps. The steps are presented in the following sections.

3.3.3.1 Step 1: Target setting based on business environment

This step aims to find areas of the business environment in which rationalization of the product variety could bring benefits and also set goals for the modular product family from the business environment point of the view. First thing is to select the product assortment which is examined closer and this process is applied to. Narrowing the scope of the research makes it less complex but it also limits the benefits to a local level. The wider the selection of products and the scope, bigger benefits might be achieved if the complexity does not increase too much.

One of the tools to achieve these targets is called Company Strategic Landscape (CSL) which is illustrated in Figure 12. CSL is presented by (Juuti et al. 2007) and closer discussed in (Lehtonen 2007). CSL describes the different organizations and key entities related to product structuring as well as relations between them.

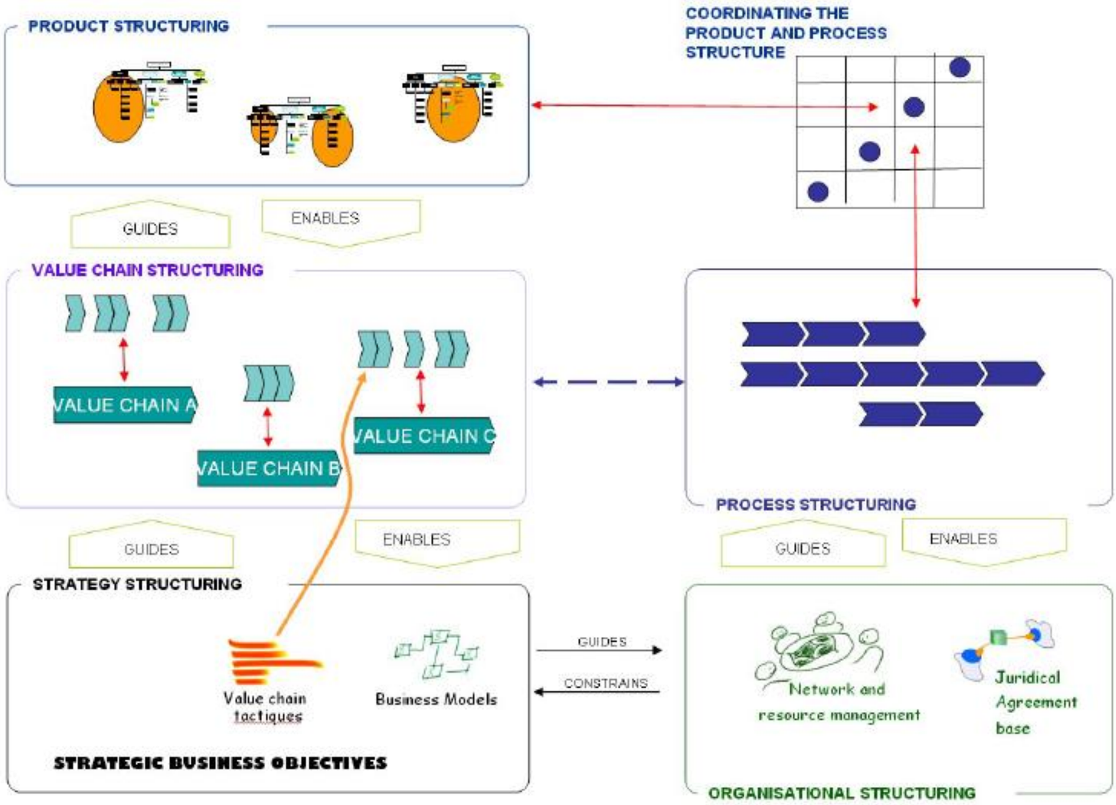

Figure 12. *Company strategic landscape framework defines the elements related to product development operations and the production of the company (Lehtonen 2007 p. 97)*

The goal of using this tool is to understand what requirements for the product modularity is set by critical value chains and different processes as marketing, logistics, manufacturing, sales and purchasing. Lehtonen (2007) emphasizes the relation between the internal structure of the product and the delivery process as the key idea of CSL. To be able to optimize product structure and delivery process operations they must be synchronized. Because of this, a multi-disciplinary group of participants is beneficial to understand all the drivers related to product during its different life cycles.

After this first step, objectives for modular product family development should be clearly defined from business-oriented view. As all of these ten steps are linked to five aspects of the Module System, this step contributes to partitioning logic by giving business perspective for partition of the product.

3.3.3.2 Step 2: Generic element model of the Module System

Second step aims to define generic elements of the existing products which are supporting preliminary module division making. Pakkanen defines generic element as an abstract element in product structuring which can be for instance, sub-systems, function carriers, assemblies or single parts. These generic elements are selected according which entities the current products consists of.

When defining generic elements, business objects stated in step one should be kept in mind. Also commonalities between selected generic elements should be avoided.

Existence of these commonalities increases the risk of unnecessary variance within the product family. Therefore it should be considered if two elements with commonalities could be represented as one generic element. Pakkanen proposes using so-called 100% rule to check the correctness of the chosen generic elements - does the suggested generic element model represent all the products chosen for the BfP?

The step works as a starting point for architecture and product structure defining, creating a list of elements for preliminary module division. These elements are defined more accurately in later steps of this process.

3.3.3.3 Step 3: Architecture: generic elements and interfaces

After choosing the generic elements, next step is to form layout that determines location of generic elements. Interfaces between these generic elements must be identified and defined. Interface designing in this step is necessary but identifying them enables adding modules to the product structure later in the process.

Pakkanen suggests Design Structure Matrix (DSM) as a tool to create preliminary architecture and to identify relations and interfaces between generic elements. DSM is an interactions and impacts modelling method which was developed in the 1960s and later more clarified by MIT research in the 1990s (Oja 2010 p. 61). Figure 13 illustrates interface recognition with DSM method. From the figure we can see that generic element 1 has interfaces with generic elements 2 and 3.

DSM for interface recognition	Generic element 1	Generic element 2	Generic element 3	Generic element 4	Generic element 5
Generic element 1					
Generic element 2	x				
Generic element 3	x	x			
Generic element 4		x			
Generic element 5			x		

Figure 13. *A generic DSM pointing out interfaces between generic elements (Pakkanen 2015 p. 192)*

In this stage architecture design with specific tools, for example CAD, might be premature and too difficult to execute. According to Pakkanen suitable tools for visualization of the product architecture in this step are basic graphical office tools like Microsoft Visio. The BfP aims to define location of the generic elements and interfaces between them. This information will be used as an input in step 7 when the detailed design of modules and interfaces are done.

3.3.3.4 Step 4: Target setting based on customer environment

When designing new product, knowing the customer requirements and customer way of using to product thoroughly is essential. This applies also for existing product as customer requirements or the way of usage has changed since the product was originally designed. This information is needed and used for creating of configuration rules of the product.

A tool Pakkanen is presenting for this step is called the Gripen approach. This approach is based on study about truck maker Scania's Series Four truck product family. Basic idea behind the Gripen approach is to find relevant questions about how the customer uses the product. In some cases the right product can be found with only couple of question as seen in Figure 14 Scania's Series Four case.

Figure 14. *Suitable product can be found by presenting only four basic questions to the customer. (Lehtonen 2007 p. 117)*

Based on the way customer is using the product, true customer requirements and need for variation are defined. To be successful in this step the BfP assumes that the customer is already using the existing product, so legitimate information can be found about the customer habits. This step contributes to the partitioning logic element of the Module System as customer requirements affects the meanings by which the product family is partitioned.

3.3.3.5 Step 5: Preliminary product family description

The fifth step aims to create a preliminary product family description where customer requirements are linked to generic elements. Generic elements are divided to parts and assemblies. Suggested tool for this step is Product Family Master Plan (PFMP) presented in (Harlou 2006). In Figure 15 links between customer, engineering and part view are presented.

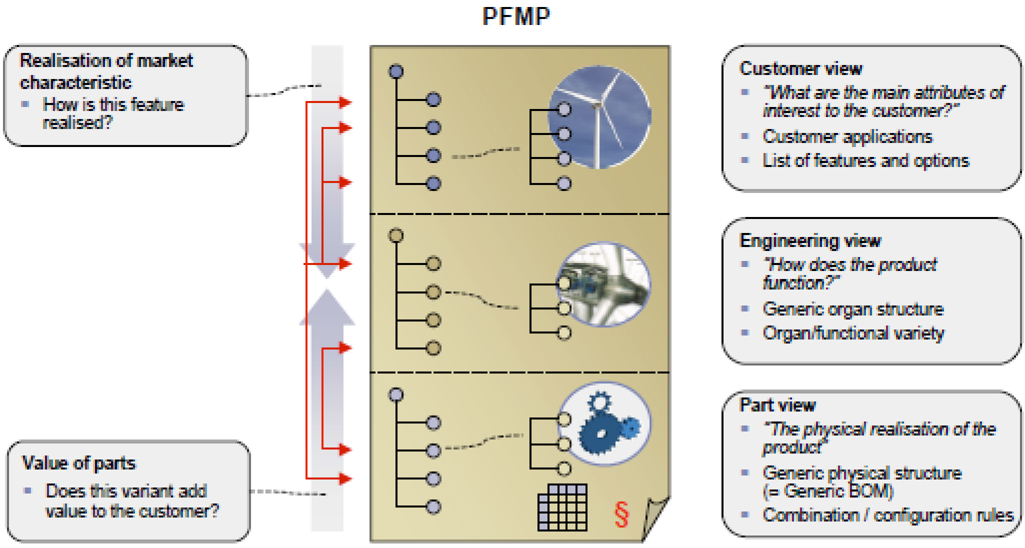

Figure 15. *A PFMP visualizes how customer, engineering and part view are linked together. (Harlou 2006 p. 129)*

Link between the customer and engineering view is considered in BfP as a link between customer need causing the need for variant and generic elements. There should be at least one generic element linked to each customer need. If generic elements are not linked to any customer needs, standardization of those elements must be considered. Elements linked to multiple needs of customer causes difficulties in modularization and thus should be avoided.

Relations between generic elements and parts and assemblies must be analyzed. All parts and assemblies related to each generic element must be defined. Good candidates for modules are generic element related part sets that can be formed with small number bill of materials. If generic element consists of a part set that is mostly standardized, it could be a configurable element. If generic element cannot be presented with standardized bill of material, it cannot be considered as a module without modifications and the element might have to be considered as a unique element, not part of the product family.

After this step the preliminary product family structure is defined. Customer needs and requirements are linked to generic elements and generic elements are defined in parts and assembly level. From Module System point of a view this step contributes towards partitioning logic, set of modules and configuration knowledge.

3.3.3.6 Step 6: Configuration knowledge: generic elements and customer needs

As the name intimates, the focus in this step is on preliminary configuration knowledge, more specifically associations between generic elements and customer requirements that are causing the need for variation. This information helps to create and illustrate product configuration in different phases of sales-delivery process and further on when designing new product family.

For these steps Pakkanen recommends using a modified version of K-matrix. K-matrix is part of the K- and V-Matrix method presented by (Bongulielmi 2003). K-matrix is a matrix where relations between customer and technical views are investigated. Bongulielmi's version of K-matrix recognizes only if there is a connection or there is not a connection between these views. BfP's addition to this is to represent four different types of relations between technical and customer view:

- Customer need requires generic element
- Customer need excludes generic element
- Customer need might affect generic element
- Customer need does not affect generic element

Going through this step, explanations of generic elements compatibility with certain customer requirements are found. These results are used in next two steps defining modules and final configuration knowledge. This step contributes to configuration knowledge part of the Module System.

3.3.3.7 Step 7: Modular architecture: modules and interfaces

The seventh step focuses on defining modules and interfaces between them. Structure of the modular project family is determined more thoroughly. Before more detail designing of the modules, generic element characteristics have to be clarified. Generic elements can either be standardized, configurable, partly-configurable or one of a kind type.

According to Pakkanen's research, detailed information about certain activities when designing modular products are kept inside the companies and not explained in academic publications. This is due to fact that knowledge inside companies related to design and management of modular and configurable product is considered as a core competence and therefore it is not given to competitors. This fact creates a problem when defining tools for this step as they are not widely available.

When designing modular product family, the aim is to include as many standardized elements as possible and minimize the amount of interchangeable standard elements in the area where variation is needed. To enable easy variation, interfaces must be standardized also. If there is no customer need causing variation related to generic elements which could be done with one solution, this generic element is a good choice for standardization.

If customer needs are creating demand for variation in generic elements, it should be researched if this element can be constructed with minimum number of standardized elements. If fulfilling customer needs with standard solutions is not possible, a set of interchangeable modules should be considered, which then are shared with the company and the product family.

Some customer needs can't be fulfilled with standardized or configurable elements and they have to be designed separately. These are so called one-of-a-kind elements. Graph on the left side on Figure 16 is representing preliminary generic element layout, an outcome of step 3 which is then divided to different kind of elements in this step.

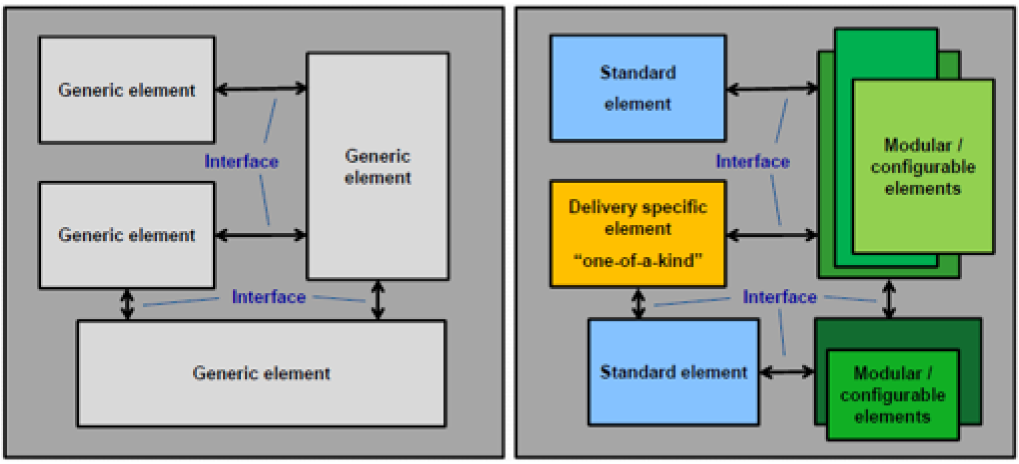

Figure 16. *Generic elements can be or consists of standard, delivery specific or modular/configurable elements. (Lehtonen et al. 2013)*

Defining interfaces between modules is as important as defining the modules itself. To enable interchangeability of the modules, all interfaces should be standardized. It is also very important to document all interfaces between modules. This documentation includes information about space reservation, geometry, structural, material, energy and signal needs. As a result of this step, modular architecture of product family is defined – what modules and interfaces the product family includes.

3.3.3.8 Step 8: Configuration knowledge: module variants and customer needs

Configuration knowledge for generic elements was defined already in step 6. In this step the key idea is to apply same methods to elements defined in step 7 and thus create more accurate configuration knowledge based on selected elements. Pakkanen suggest using the same modified K-matrix method that was used in step 6 to define relations between customer needs and modules.

V-matrix introduced by (Bongulielmi 2003) can be used to visualize compatibilities between generic elements and their contents. Results of this step can be used in sales-delivery process to clearly present the variants and needs related to them. This step also helps creating different software based sales configurators and is helping the creation of documentation behind the product family.

3.3.3.9 Step 9: Product family documentation

In BfP, results of every steps are documented within the specific step. This step 9 is general documentation step of the BfP. Its purpose is to show reasoning chain that considers product family, generic elements, solutions within generic elements and customer needs as well as relations between these. Pakkanen suggest using a graph called Product Structuring Blue Print (PSBP) as a tool for this documentation. Generic example of PSBP is presented in Figure 17 below. In PSBP the product family is divided into generic elements and those are further divided into solution principles within generic elements. As discussed earlier these solutions can be either standard, configurable, parametrical or one of a kind. Customer needs are then mirrored to these solution principles.

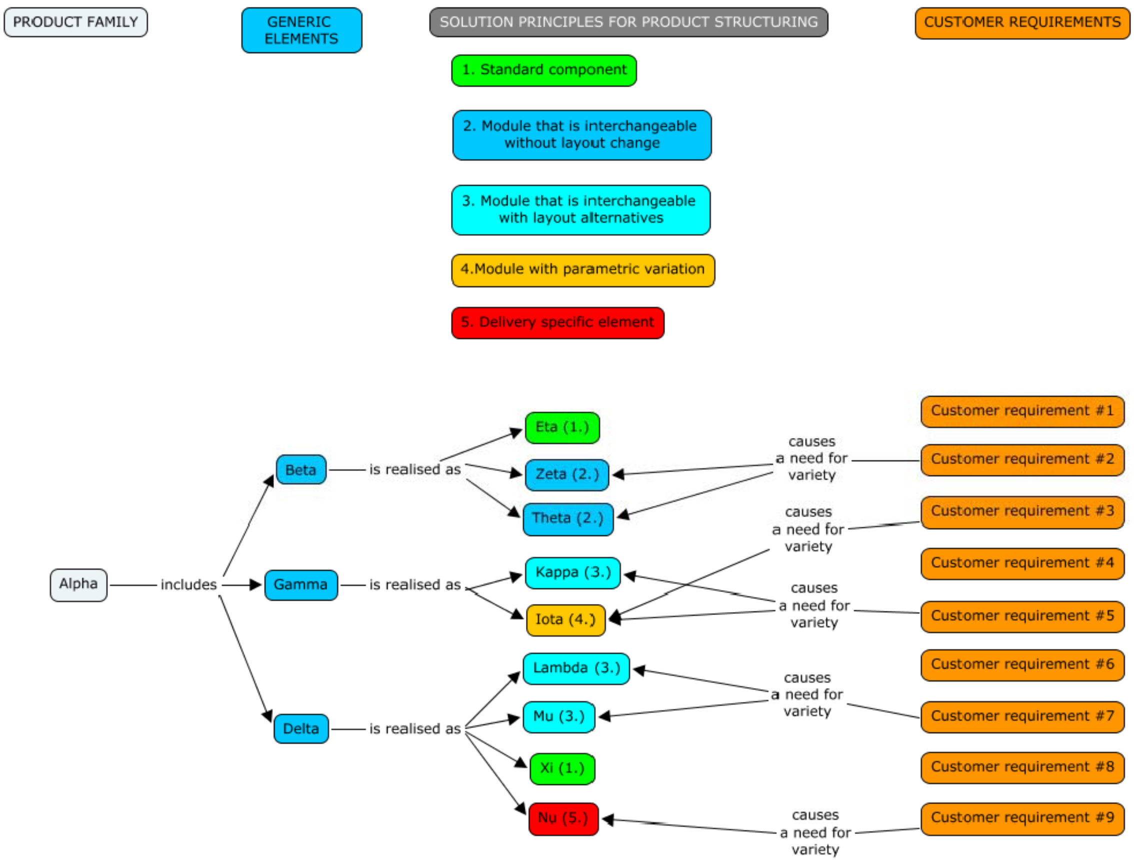

Figure 17. *Generic example of Product Structuring Blue Print. (Lehtonen et al. 2013)*

This documentation is helping design work by supporting re-use of existing designs. PSBP is also a good way to document product family structure during its life cycle evolution as new design and features are applied.

3.3.3.10 Step 10: Business impact analysis

In step 10 business impact of the designed product family is investigated to see if the new product family design ended up being competitive. This is very important phase as the BfP is based on business oriented view of modular design process. Business effect are investigated for the whole life cycle of the product family.

Pakkanen has created overall model for analyzing the business impacts. The generic model is presented in Figure 18. Left side of the module consist of five steps of the

Module System to which every step of the BfP contributes. In the middle there are guiding principles and mechanisms which are describing possible objectives, phenomena and problems that modularization can have an effect on. Arrows between the Module System elements and guiding principles are relations describing which elements have effect to which principles and what type of the effect is. Right hand side of the model describes generic process steps of the manufacturing industry and resources needed for them.

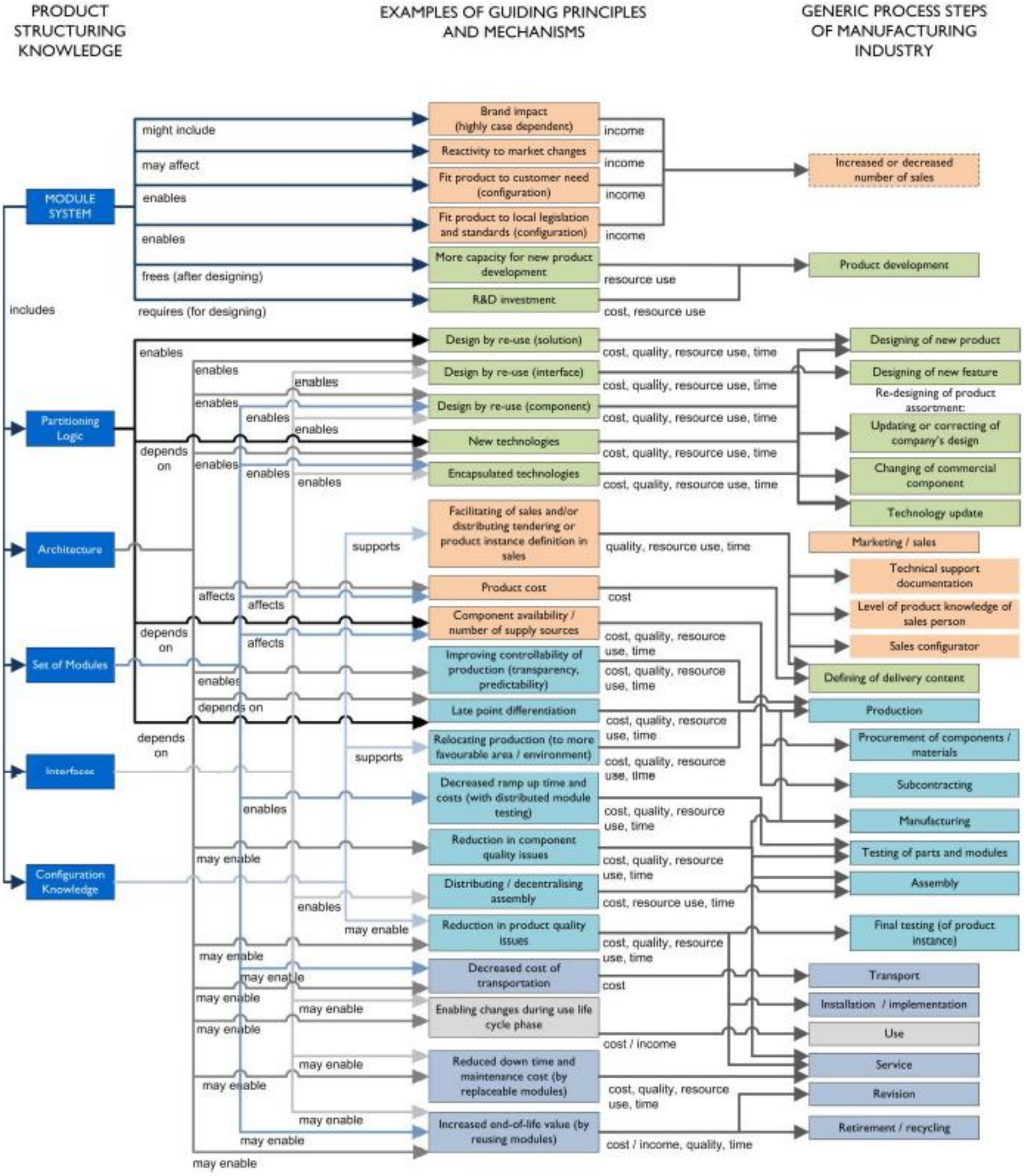

Figure 18. *Business impact analysis model for the Module System. (Pakkanen 2015 p. 215)*

Result of this step should be an estimation of business impact of the successful modular product family development project. This result will indicate whether the design is worth of proceeding or if there is a need to do some iterative rounds to improve the design and business effect. As Lehtonen stated (Lehtonen et al. 2013): “When you modulate, focus on the product and its execution, but always follow the money.”

4. SPACE RESERVATIONS IN LITERATURE

Every time when designing a configurable and modular product there has to be an understanding about spatial requirements of different modules. Quite often there are no certain systematic methods how companies handle these situations. Therefore this chapter focuses on the topic of this thesis from the viewpoint of the related literature. First, general thoughts and ideas about the role of space reservation in configurable product design process is discussed. After that, some different space reservation models are introduced.

4.1 Role of space reservations in design process

Step 7 of the BfP concentrates on dividing generic elements to standardized, one-of-a-kind and configurable elements as discussed in the previous chapter. Important part of the modular architecture design is to define spatial needs of the different elements. For standardized elements defining the physical space is not that complicated when it can be considered as a normal design work. In case of configurable elements or modules it is much more important to study and analyze if all the different variants can fit in the same position, as well as mate with the interfaces. Pakkanen (2015) argues that ideally in a successful design process all interfaces and space reservations should be recognized and defined in modular product architecture.

Modular design process aims to offer great external variance to satisfy customer requirements while simultaneously minimizing the inner variance to cut costs and support product management. Quite often increasing external variance will also cause higher inner variance which should be avoided. Architectural standards are tool to fight this. Kreimeyer et al. (2014) are dividing architectural standards into three different entities which are shown in Figure 19.

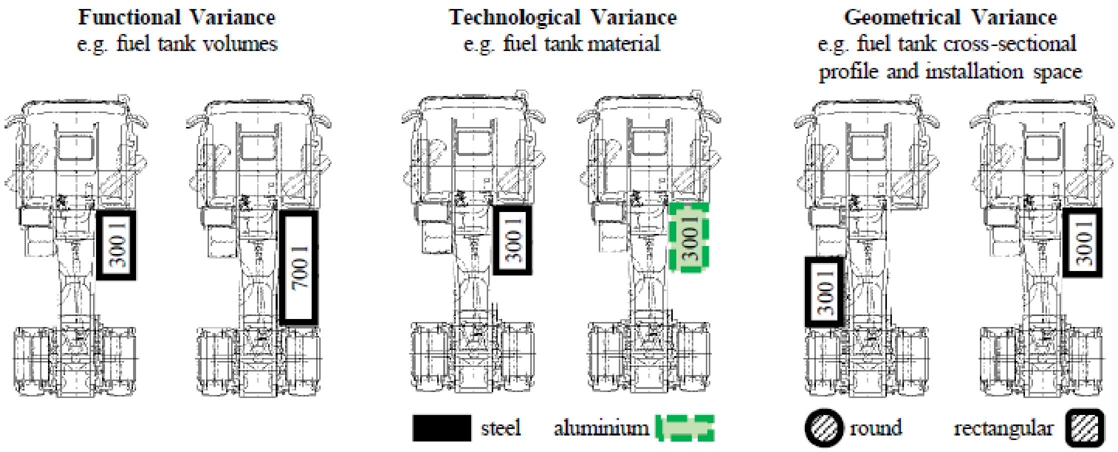

Figure 19. *Three different types of variance related to architectural standards. (Kreimeyer et at. 2014 p. 7)*

Functional standard refers to the function of the element, in this case different volumes of the fuel tanks. Technological standard describes material and manufacturing technology of the tanks. Geometrical variance can be divided into two different cases – part related, exemplifying the shape of the tank, and position related defining the location where the tank is installed. Combination of these three different standard is the fourth standard, which is interface standard. From the space reservations study point of view, positional and interface standards can be seen as the most interesting ones. (Kreimeyer et al. 2014 p.7)

By defining geometrical standards and technical interfaces at early phase, based on low detailed conceptual geometry, more detailed design is supported and proper architectural layout created. Reserving standardized installation spaces and unchangeable interfaces the designing of single modules can be divided to different parties. To minimize constant changes to product, future innovations and changes should be planned. Dependencies between the old and the new solutions has to be acknowledged, which might mean including some supplementary interfaces for the future needs. (Kreimeyer et al. 2014 p. 7-8)

Generally in literature related to modularization and modular project design processes, the concept of space reservation modelling is mostly covered by emphasizing the importance of interface definition, design and management. Also the interchangeability feature of the modules is highlighted. This includes reserving installation spaces for variants but detailed methods for space reservations are not explained.

All in all, space reservation thinking is very important part of modularity. It enables the interchangeability of modules. When done carefully it can also considerate possible technology evolutions and regulations driving new modules and interfaces.

4.2 Space reservation models

One key initiative for this thesis was lack of space reservation models used in companies which would be presented publicly in the literature. However one of these pieces, the MAN-approach is presented in this section. Also other methods, found from the literature, for modelling spatial requirements are introduced.

4.2.1 MAN-approach

Many companies struggle with growing number of product variants over the years. Common solution to this is to apply a modular system approach to reduce and control the different variants. This was also the case with MAN.

MAN Truck & Bus AG (MAN) is a German commercial vehicle manufacturer which has specialized in producing small, medium and heavy duty commercial vehicles for a large number of customer needs. These requirements are coming from wide spectrum of customer use cases and different transportation tasks as well as requirements coming from worldwide markets. To satisfy all customer needs they have been creating new features and variants. During the past years, the number of different basic truck configurations exceeded 15 000 variants. And this number is excluding all the detail configuring of the product which would take this number up to 10^{46} possibilities. This amount of variants was causing them unnecessary costs and made product management difficult. Giving up high-variant product portfolio was not an option for MAN as they considered it as a strategic competitive advantage over other manufacturers. (Förg et al. 2014 p. 754; Kreimeyer at al. 2013 p. 3)

This evolutionary growth of a diversified portfolio coming from satisfying the customer needs caused also some negative consequences mostly related to inner variance. Therefore MAN conducted a study to reduce costs and inner variance while maintaining the ability to satisfy all customer needs. MAN focused on creating Modular Kit Truck to handle these requirements. (Förg et al. 2014 p. 756)

Modular Kit Truck is based on usage of architectural standards, introduced in the previous section. Following building blocks are used for developing the standards according to Kreimeyer et al. (2014):

- Future roadmap and technical change propagation planning
- Generic package space decomposition
- Conceptual design tools and product models

Future innovations and changes are systematically planned. Future roadmap is illustrating technical dependencies between old and new components. This is done to define necessary interfaces and installation spaces for future compatibility. Change propagation of the components is studied using Change Prediction Method (CPM) which was developed by Clarkson et al. (2001). The results of CPM are then analyzed with DSM-matrix method. (Kreimeyer et al. 2014 p. 9)

MAN offers a wide selection of different basic models from which customer can select the most suitable one. After picking the basic model, the customer will specify it to a complete vehicle by picking desired features. This large variety of features causes many different package arrangement patterns for components. Normally this would cause high inner variance but MAN handles this problem with their idea of a generic package space decomposition which is a crucial part of Modular Kit Truck and second step for creating the architectural standards. (Förg et al. 2014 p. 759)

The basic idea of the generic package space decomposition is to divide the product, in this case a truck, to sectors nominating available installation spaces. This division enables analyzing and planning of different layouts during early phases of the design process. The sectors are based on generic, always appearing vehicle elements, such as axles, cab and the frame side members. Parametrically defined collateral planes are dividing the structure to total of nine different sectors presented in Figure 20. The number of the sectors is dependent of the basic structure of vehicle, if there is fewer axles, there will be fewer sectors as well. (Förg et al. 2014 p. 759-760)

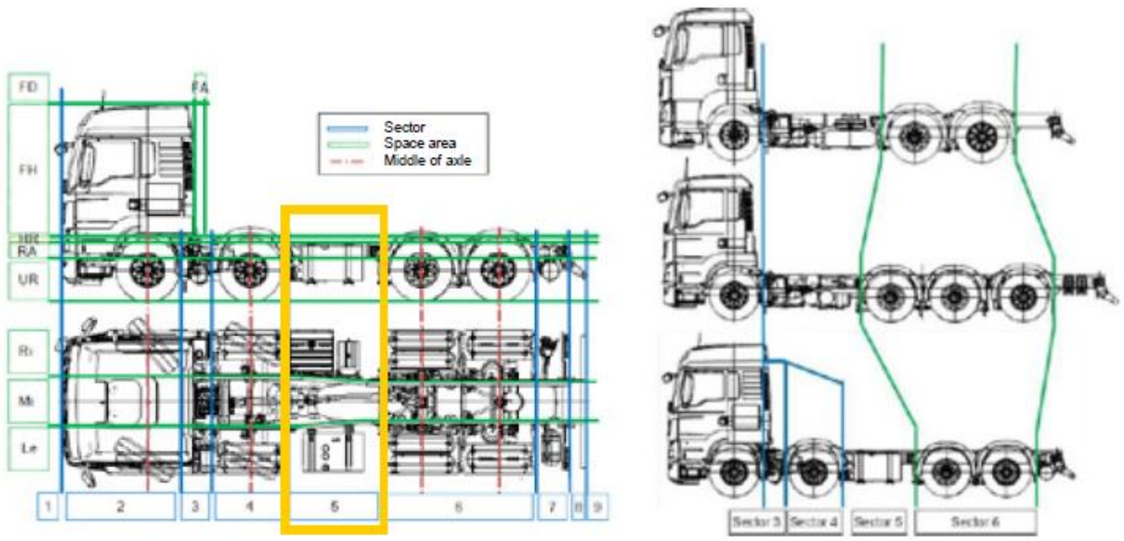

Figure 20. *Sector division of the truck. (Förg et al. 2014 p 759)*

In their study to reveal the main areas of variance MAN found out the sector under the cab to be the most complex, but the area between front and rear axles proved to be the one with most component arrangement related variety. This sector five, marked with yellow in Figure 20, contains for example, fuel tank, AdBlue tank, exhaust systems, battery container and spare tire just to mention few possibilities. All these mentioned components comes in different sizes and shapes according customer needs and requirements. Also constantly changing and tightening emission regulations, defining the exhaust after treatment system, have a great effect on this sector. Available installation space for these components varies according the selected base truck model and its wheelbase. Figure 21 is presenting couple of possible configurations for the assembly. (Förg et al. 2014 p. 760)

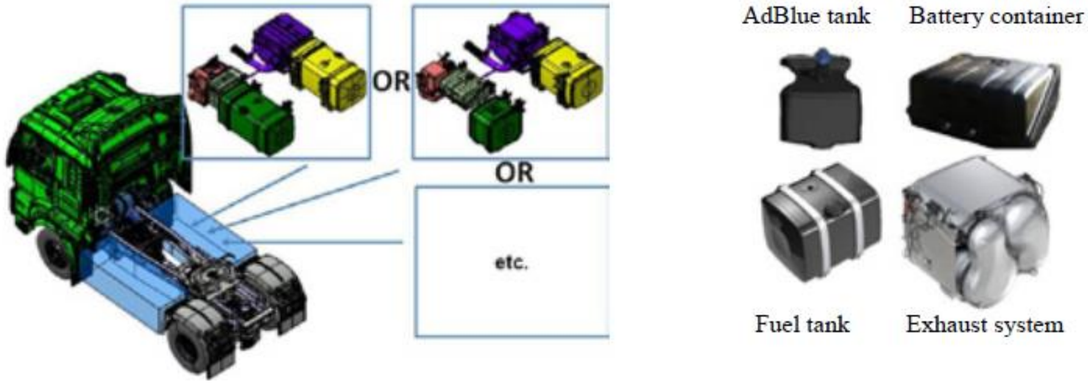

Figure 21. *Sector five, blue boxes highlighting the possible installation spaces for the different equipment on the left. (Förg et al. 2014 p. 760)*

If taking into consideration all the possible configurations, there are countless number of different layouts. Due to this fact, MAN created a large number of different layouts representing different possible configurations mounted in different basic vehicle models. To create certain layout formalization rules they carried out thorough interview across different experts within the company. The four models evaluated in the process are seen in Figure 22.

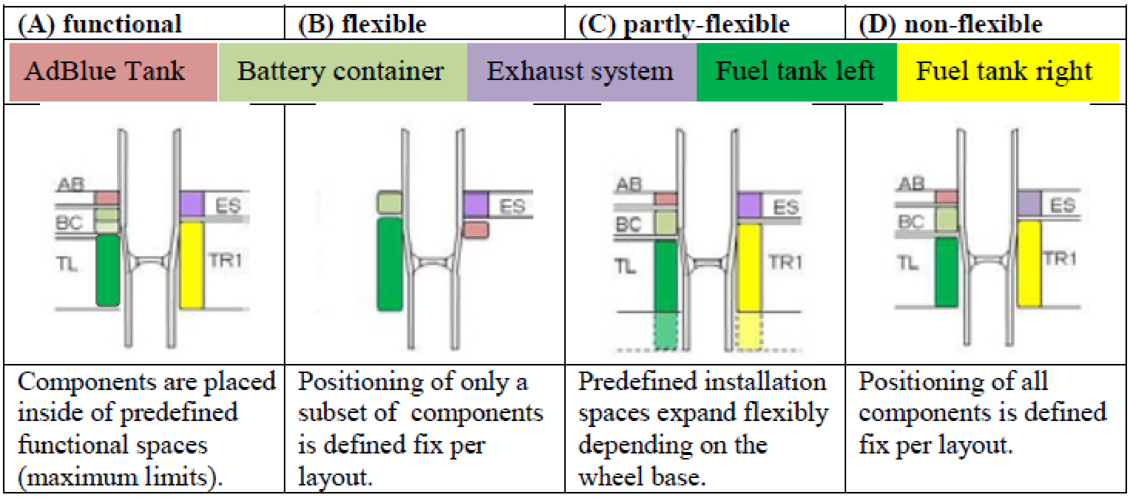

Figure 22. *Four layout models which were studied. (Förg et al. 2014 p. 761)*

A functional layout (A) defines the borders in which the components have to be located in. Inside these limits components can move and vary freely. This means than in design phase only the maximum dimensions have to be defined for all components. A flexible layout (B) defines only positioning for a certain component allowing other components' size and location to vary freely. A partly-flexible layout (C) predefines installation places but allows for example fuel tanks to expand according the selected wheel base. A non-flexible layout defines functional installation places and their exact leading and rear edge. In their study, MAN found the option D, the non-flexible layout, to be the most suitable for their purposes. Models A-C offered more flexibility, but at the same time the flexibility caused troubles managing all the different layouts. Functional layout enables moving components within the limits but every different position has to be named differently which will increase the number of total layouts. The non-flexible layout D can reliable define the functional installation spaces available and therefore it was the one to be chosen. (Förg et al. 2014 p. 761-761)

The starting point for architectural standards are received from the change propagation methodology, which are after evaluation, used to create documentation in a form of the generic package space decomposition. Architecture Digital Mock-Up tool, shown in Figure 23, is used to analyze different architectural standards. Created standards are simulated for certain desired part of the product portfolio to see if they can be applied to every variant. If there is a collision in the model, either the standard has to be changed or the affected product concepts has to be approved off-standard. Suitable architectural standards are specified and they are supporting the further design process of the vehicle. (Kreimeyer et al. 2014 p. 11)

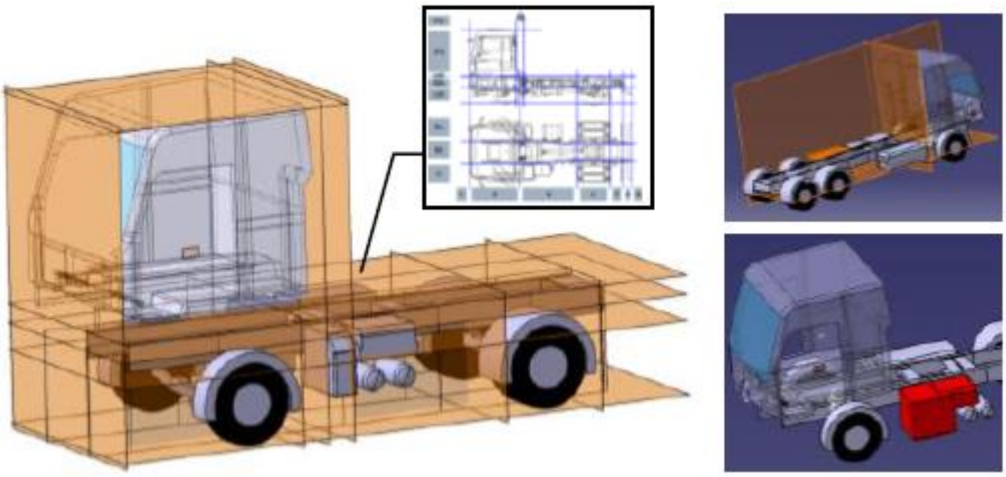

Figure 23. *MAN's component integration analysis tool. (Kreimeyer et al. 2014 p. 11)*

According to Kreimeyer et al. (2014) this kind of product development creating architectural standards will lead to a stable and transparent vehicle layout. This will enable less inner variance because of modularization enabled by early specified interfaces and allocation of package spaces to components.

4.2.2 Other methods

There are many other methods to create space reservation for modules and components, but not many of them are well documented in the literature. Most commonly in different studies related to modular design processes it is only stated that interfaces and spatial requirements have to be taken into consideration.

One of these other methods about space reservations for configurable products is introduced by Holmqvist in his dissertation (2004). He studied also modularity in truck manufacturing industry where his example of this stop zone method, seen in Figure 24, comes from.

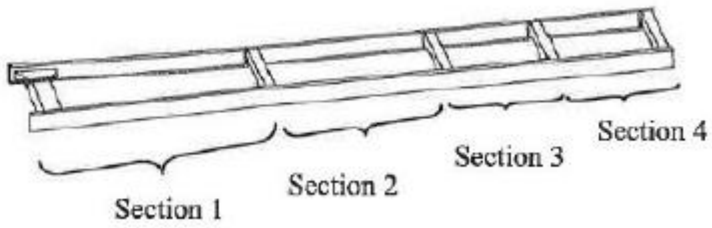

Figure 24. *Holmqvist presents truck chassis in sections that the variance is handled within. (Lehtonen et al. 2013)*

In this method the variety of the product is handled within each section in such way that change to one section is not affecting the section next to it. If the sections are designed to stay independent, a new design can be applied to other sections without need to change the whole chassis. Areas between the sections where two sections meet are considered as bases. These bases, which are presented in Figure 25, are preventing the variety to spread from sector to another. Holmqvist suggest that a good place for a base is one where the product, including interfaces and parts, stays as constant as possible.

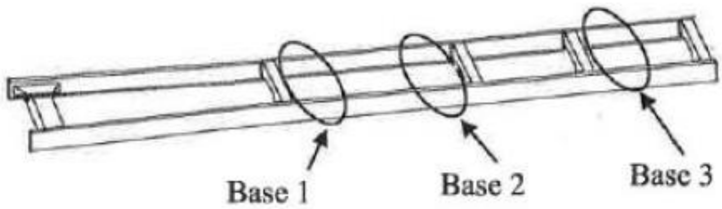

Figure 25. *Bases are dividing the sections and preventing variety to spread. (Lehtonen et al. 2013)*

According to Holmqvist, not all interfaces necessarily have to be bases. Actually he states that a base should usually be a combination of several interfaces between the sections. If all interfaces would be considered one by one between the variants, creating common product architecture would not be successful and each variant interface would be unique. Holmqvist also states that this stop zone method is useful when there is a large number of variants, different technologies and large size differences between the variants. In these kind of cases it important to focus on interface design as it might prove to be impossible to define interfaces after defining a large number of different variants.

In a top-down design process the function of the part or module is defined before the part itself is designed. In this kind of design processes, skeleton modelling can be used also as a space reservation modelling tool. Skeleton modelling is widely used with CAD software. Its idea is to first create a base geometry needed for product architecture design before the component itself is designed. This can mean for example planes limiting the dimensions of the component. Example of skeleton model of an electrical motor shown in figure. (Laukkarinen 2014 p. 34)

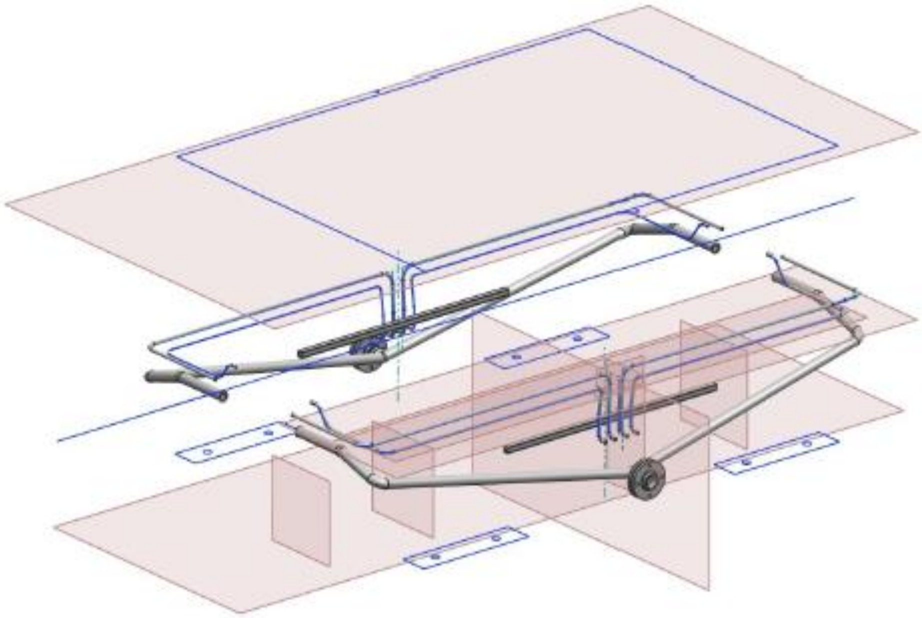

Figure 26. *Skeleton model can include planes, interfaces and solid objects. (Laukkarinen 2014 p. 66)*

For space reservation purposes this model of electric motor is quite complicate, but it shows that also interfaces and some certain components, in this case oil piping, can be done in the skeleton model. These models can be made also parametrical. This could be used for example in MAN-case when wheelbase is increased, also the space reserved for component between the axles could increase. In general this is already a bit more detailed way for space reservation but still a robust assembly modelling method if the components or the modules are not yet designed. (Laukkarinen 2014 p. 34-36)

5. CASE: KONECRANES

As discussed earlier, this thesis is a part of larger modular product design process. This chapter explains reasons behind the project that started the idea of modular product. It also presents the current situation of space reservation thinking and modelling in the company and describes how methods discussed in the previous chapters could be used in this development project.

5.1 Company introduction: Konecranes

Konecranes is a world leading group of Lifting Businesses^{TM}, serving a broad range of customers, including manufacturing and process industries, shipyards, ports and terminals. In 2015, group sales reached EUR 2,126 million. Konecranes has 11 900 employees at 600 locations in 48 countries. Its business can be divided in to two different areas, equipment and service. Equipment business area offers a wide range of components, cranes and material handling solutions for different industries including process industries, the nuclear sector, ports, intermodal terminals, shipyards, and bulk material terminals. In service business area, Konecranes is the market leader having over 450 000 different units under its service contracts. (Konecranes 2016)

5.2 Reasoning behind modular product development

As stated earlier in this thesis, the literature around product development focuses mostly on developing totally new products. Within the industry, especially the more traditional industry like machine industry, the more common way of product development is incremental designing. This is also the case with Konecranes. Although there are several product development projects trying to find totally new and revolutionary innovations that would change the world, the main focus is in developing existing products. Oja (2010) lists two main reasons why companies engages in product development:

1. Increasing product value by improving product functions and properties that respond to increases in customer requirements and/or separation from the competitors.

2. Decreasing realization cost of value and product costs.

According to Oja (2010) companies tend to focus their development on existing products and product concepts because they have a long history and knowledge with existing solutions. Also customer requirements usually are based on the existing offering in the market. It is not so common that customers require something totally new as it is much easier and logical to think some improvements for existing products. This also means that developing something totally new and introduce it to the customer can be considered as a significant risk. For such conservative industry as machine industry customers tend to stick on already proven solutions. Market penetration with a new product in this industry is much harder compared to for example customer electronics where there are usually this group of early adapters who are willing to try all new appliances on the market. In the machine industry, purchasing totally new equipment is a great risk for the customer and therefore they would like to see some someone else to buy the first product. It is also noticeable that the product itself or certain technical feature is not what customer is paying for but the added value to customer process which can be achieved with the product.

According to Oja (2010) ideally in incremental product design, designing of the new feature should happen separate from delivery projects. Designing new features as a part of delivery project creates a significant risk for cost and schedule overflow. This means that customer requirements should be recognized on early stages from the market, before the actual delivery project takes place. This way the product development can be carried properly and the developed feature can be applied to the product when it is already fully proven. Of course this is not always possible. Sometimes companies has to evaluate the risks of doing product design during delivery project to make the business to happen.

The product, which the modular design project behind this thesis is about, has been around markets for long times. Through the years it has been evolved because of altering customer requirements and self-driven incremental development. It has not been always the case that product development and new features would have been designed separately from the delivery projects, which in some case have lead for a solution which is not probably the best for the whole product portfolio.

In the beginning, the variations were made to the original product as project specific elements. When the same customer ordered the product again, with some alterations of course, the new delivery project was designed according the previous project. This was the fastest and the most convenient way of designing which would allow re-use of the old design.

Through the years of delivery projects, the product variety grew and expanded like a tree – new design as a branch from which more new designs were evolving. This has been causing difficulties in the product management. Branching of the product portfolio has caused that some of new features designed are not fitting anymore to all variants without redesigning. From this background, rose the idea of having a modular product, in which all, or at least most of the variants would be based on.

As mentioned, in earlier study about design process of modular project architecture at Konecranes, Niskala (2014) ended up using MFD method. Since that the knowledge about the Brownfield Process had grown mostly because of Pakkanen's dissertation and know-how of Tampere University of Technology professors who were advising in this development project. Therefore the guideline of this modular design process was chosen to be the Brownfield Process along with simultaneous incremental design which this time could be done completely separately from the delivery projects.

Target of this project was to cut inner variance and design need during delivery process, support product management as well as support the idea of life time modularity. All this should be accomplished while maintaining the external variance, since fulfilling customer requirements can be considered as a lifeline for the business.

5.3 Role of space reservations

This section discusses about the current product variety which is under modularization. The solutions causing spatial difficulties for the design are introduced as well as found solutions and improvements.

5.3.1 Current status of spatial features

The product is consisting of the base unit to which all larger elements are attached to. This kind of assembly type was closer examined when MFD's "base part" assembly was discussed. Some of these elements can be considered as standard which are always attached to the base unit with standardized interfaces.

The base unit's dimensions are changing within the product variety. These dimensions can be divided to three different types according how they vary. First dimension is fully parametrical and specified by customer. There is no reasonable way to standardize this without jeopardizing the business. Luckily this dimension is only affecting minor components and part of the base itself. Second dimension can be considered configurable. It has few different options what it can be. This dimension comes also from customer requirements and therefore is impossible to standardize. For third dimension there is two different options. These options are coming from the past where two different variants have been designed.

The third dimension is the most troublesome as it has an effect to almost every component in the product. This means that some design to other dimension might not fit at all to the other dimension base. It is not straight related to customer requirements, but it is deriving from technical solutions which then are coming from customer requirements.

On top of this there has been some other changes to base dimensions. These are coming from certain regulations which were nowhere to be seen when the product was originally designed. Due to constantly evolving safety and environmental regulations, size of some elements has grown so much that the base unit has to be changed. As discussed earlier these changes in the base unit are causing major redesigning and are often noticed not until the delivery process.

5.3.2 Standardizing installation spaces

From the current status analysis, it can be easily seen that changes in the third dimension of the base unit is causing large quantity of inner variance although it only offers one technical solution to customer which is not related to other things affected by the base unit change. Based on this analysis and the conducted Brownfield Process study it was found critical, for creating one product from which others can be easily configured, that the third dimensions of the base unit is kept standardized.

Standardizing the third dimension starts by analyzing the two different technical features causing these variants. This study includes quite deep research about the cost of both solutions, costs and technical possibilities to combine these solutions to enable the use of standardized base unit’s third dimension. It has also to be considered if the other variant could be removed totally from the product platform. The issue is not just technical but it also requires market analysis and consideration between added value to customer, costs and market offering.

The second dimension can be thought as configurable, having few different options, in between which the steps are equally sized. This way the variance caused by this configuration can be handled with standardized modules, which number depends on the chosen configuration. The third dimension could be possibly handled by creating parametrical 3D-model, which would even more reduce the amount of design work during the delivery process.

5.4 Space reservation modelling

Section 4.2 concentrates on introducing couple of different ways to model necessary spatial requirements for different variants. This section focuses on discussing what methods are used for space reservation modelling for the product now, and would it be useful to apply methods from the section 4.2.

5.4.1 Current status

Generally back in the days Konecranes philosophy for project design has been to fit the most powerful option to smallest possible place. It has roots in one-of-a-kind design and also in engineering pride to create the best possible product. This certainly works for a unique product offering aiming to fill customer requirements, but it does not serve the concept of a modular product platform.

During the development of the current product, designers have focused to create the most efficient and working solution around existing elements and features. Not all possible configurations of even current elements have been taken in to consideration, which then has later created issues with scarce installation spaces or even component collisions. This has been of course the case with possible future variants.

Designing of the product is currently done using a 2D-design program, AutoCAD. This sets already some limitations for visualization of different options as well as collision and dynamic modelling of the components. Space reservation modelling usually needs 3D-design for supporting, even though experienced designers can deal this with 2D.

All in all, it can be concluded that the concept of space reservation has not been a driving force guiding the design in the company in the past decades. This has probably been more a state of a mind decision than company driven design guideline. It can be still said that a modular way of thinking has been on the rise in recent years, which could indicate also changes for space reservation thinking.

5.4.2 Improvements

In the start of this thesis there was an anticipation that the MAN method would be the most suitable way to model space reservations for this project. In MAN's case the number of different wheelbases, meaning available assembly space, and different configurations of components installed between the axles is much larger than in this case. Actually the aim is to standardize the third dimension which would standardize the installation space having the most variance within its configuration of elements.

A second matter affecting space reservation modelling is the nature of components used in this most varied area. Generally all components which are in-house design in this area will be tried to keep standardized, so if a certain option is selected, there is one predesigned component filling that purpose. The components or elements which are not in-house design are the ones causing the most variance. These components are mostly ready made from the shelf commercial components. This actually simplifies the process of space reservation substantially.

Sufficient results can be achieved by recognizing the different component in this varying area. This step includes investigating imaginable future changes due to new requirements related to environment or safety. It is a worth of taking to account potential future technological inventions and trends, especially their spatial and interfaces requirements. After identifying the possible components, study for technically possible different configurations should be carried out.

One major step in this modular development project is a change from using 2D AutoCAD to 3D-designing with Siemens NX. Although by itself it does not have an effect on the product, it will enable better visualization and support configuration of the product. The different configurations can then be verified with products 3D-model.

Part of the design process is to define what configurations are included in the product base structure. In this study, the frequency of the feature has to be evaluated with the costs coming from including the space reservation and interface in the base as well as costs coming from unique design work if the configuration is not included in the base product. This step will be the base work for creating configuration rules which are then later guiding the sales-delivery process.

In the previous section, importance of installation space was highlighted. This section discussed about possible component configurations. After study of possible configurations, necessary interfaces for different options should be included in the product base unit. This will enable the configuration during the delivery process. Making interfaces for all variants raises the production cost of the base unit, but at the same time it enables later component swapping in the delivery process. It also makes much easier for the customer to retrofit the product with new technology without having to change the whole base unit.

6. RESULTS AND DISCUSSION

This chapter answers to research questions which were asked in the beginning of this thesis. Based on findings, improvements for existing design process are presented. Results from previous chapter's actions are discussed here, as no measurable outcomes are yet available.

6.1 Answers to the research questions

The research objective of this thesis was combined in four different questions. Complete answers for these questions were discussed in the chapter 4 and 5 but here they are reviewed shortly.

- What is the role of space reservation in configurable product design?

Space reservation enables component swapping and lifetime modularity within the product by defining needed installation spaces and interfaces for different modules.

- How space reservations should be taken into account in this ongoing product development project?

By standardizing the dimensions for the installation space having the most variability, space reservation modelling will become more straightforward. This will reduce the number of different possible variants of the base unit.

- What kind of different space reservation methods exist?

Companies are using different methods, which are not widely presented in the literature. This thesis focused mostly on MAN-method, in which non-flexible layouts are created for different basic variant products. Other introduced models are restricting space by defining interfaces and creating planes or borders within each element has to stay.

- What is the most suitable method for this ongoing product development project?

In this case, amount of different configurations are reasonably low. Together with the fact that the base unit will be standardized, this gives not enough reasons to specialize in space reservation modelling. Most common and likely appearing configurations can be easily manually checked with 3D-design tools whether they fit to available installation space or not.

6.2 Improving design process

Current project design process model in Konecranes is not considering space reservations separately. Interface design is one of the checked steps in the current engineering process but it is more related to an interface between the product and customer facility. Interface design within the product, between different elements and components is not individually mentioned.

Therefore one of the main objectives for this thesis was to add steps to existing design process which would consider modular product design and spatial requirement thinking. As it was discussed earlier the Brownfield Process aims to create a modular configurable product, which is also the goal for this ongoing modular product development project.

The suggested additions for the current design process is presented in Figure 27. It must be noted that it is not the complete design process, but it is showing only the relevant steps where these proposed steps are affecting. This suggestion is based on that the product has a clearly defined element structure and configuration knowledge following the steps 7 and 8 of the BfP.

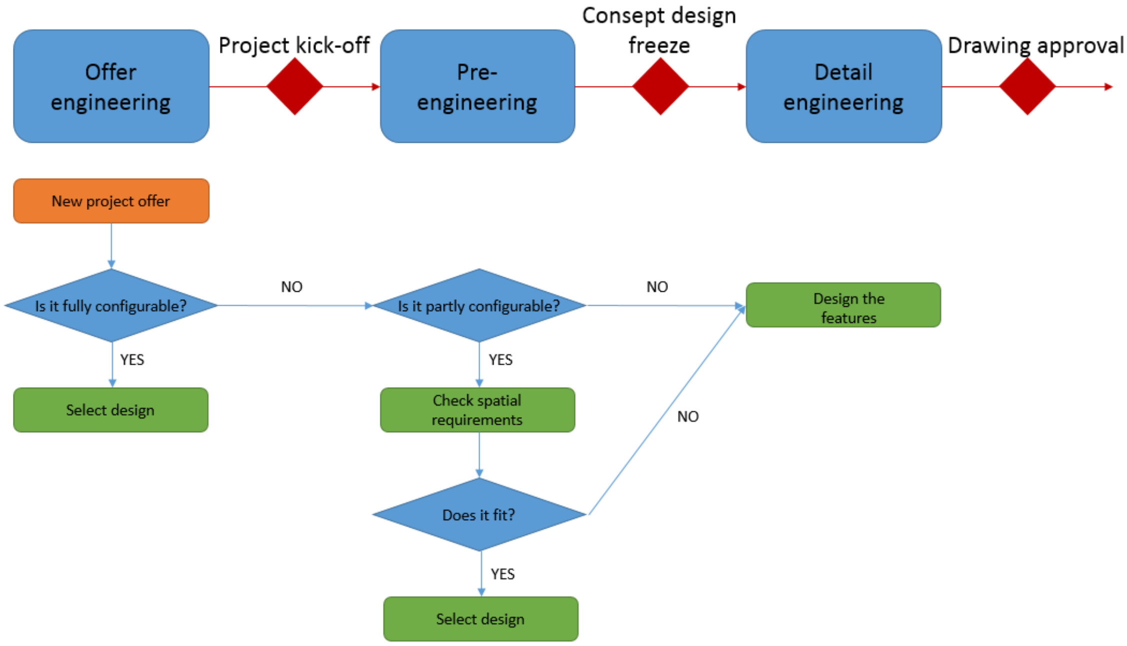

Figure 27. *Proposal of new steps to project design process.*

The process starts from offer engineering, where based on customer requirements coming from open tender, offer engineering will check if these customer requirements can be filled with fully configurable, partly configurable or one-of-a-kind tailor made elements. If the product can be configured from already designed elements during the offer stage, there is no separate need for a delivery project specific design. This method can be also applied separately to different entities. This is made possible by base unit assembly, where different elements have interfaces only with the base unit.

If the product cannot be fully configured during the offer phase, which will be the most common situation, the next step is taken during pre-engineering stage of the delivery project. Pre-engineering takes place in the very beginning of delivery project. At this stage there will be some already designed elements and some tailor made elements. Chief design engineer will evaluate whether these tailor made elements can be designed and installed for the space left after the configurable elements are installed. If this spatial check is passed, configurable element design is frozen. If not, the whole entity has to be redesigned. Elements that were not yet configured, will be designed in the detail engineering phase.

In this model offer engineering has a significant role of understanding the configuration knowledge coming from the BfP and its relation to customer requirements. In this phase, when the project delivery time is not running, it is important to recognize if customer needs are causing need for project specific detail engineering. Ideally the product would be fully configurable, but this is not reality in the market of this product. The biggest variance can be still managed with reserving installation spaces for the main elements. This way special customer requirements can be filled with only small detail engineering, which can be conducted in a short time in the beginning of the delivery project.

6.3 Analysis of the results and targets for improvements

Finding answers to the research questions set in the beginning of this work has given valuable information about the role of space reservation methods and how they should be considered. However it was little disappointing how few concrete ways of modelling was found from the literature. This combined with the fact, found models were not tested by using them in real modelling, leaves the question open if the best method was really found.

The proposed design process opened eyes of some designers emphasizing the importance of thorough understanding and designing of configuration knowledge. It reflects the base idea of mass customization, modularization and Brownfield Process which are highlighting the importance of proper product development process. If this is done effectively, order engineer can handle the delivery project based on customer requirements without need for project specific design that would case extra costs and delay.

Important part of action research method is the iterative round where findings from the study are applied to the subject of the research to see how those really work. Performance of these actions can be then investigated and suitable methods adapted. Unfortunately in the case of this thesis, the project on the background is ongoing at quite modest pace. This is mostly due to vast work load coming from existing delivery projects which quite often will overlap product development work.

As said, suggested methods and design processes have not been tested in practice. Nevertheless interviews and discussions within the organization has been carried out in order to verify these actions. These have received encouraging feedback from designers and technical directors. This still does not mean that these would be the correct ways of working. Taking into account these views about space reservations are quite new and have not been systematically applied before, a new research should be conducted during later stages of the modular product development project when some concrete actions have been done.

This thesis will suggest re-evaluation of the need for layout models after all configurations included in base model are confirmed and base unit design has been started. In that stage it is easy to see if space requirement modelling can be done the more simple way of testing all the existing variants or has the number of variants grown so much that MAN-method should be applied.

Success of the proposed design process update should be evaluated after completing the brownfield process or when steps 7-9 have been completed. At this point offer engineering should try to classify and possibly create configurations based on existing customer requirements and the configuration knowledge of the product. If the offer engineering can reliably define projects to configurable, partly-configurable and one-of-a-kind, creating working configurations which then are checked and verified by designers, this process can be considered successful. If the configuration process done by offer engineering cannot be completed smoothly on test cases, the source of challenges needs to be found and evaluated. Whether the problems are caused by improper configuration knowledge or documentation, corrective actions have to be taken to fix the problems.

7. FINAL SUMMARY

The objective of this thesis was to find the ways how space reservations should be managed in the ongoing modular product development project. The thesis also aimed at finding the best possible solution for modelling space reservations in the project. In addition to this, one main goal of the thesis was to suggest new steps for delivery project design process which will take into consideration spatial requirements.

The beginning of the thesis focused on basic concepts related to this topic – ideas of configurable product, modularity and interfaces were familiarized and reasons behind these phenomena discussed. Based on these concepts, it can be stated that mass customizing is a viable option to cut costs related to product management while still meeting the wide customer requirements. Mass customizing can be achieved by creating a configurable product which consists of pre-designed modules with standardized interfaces.

The ongoing product development project follows the Brownfield Process method which aims developing a configurable and modular product based on the existing product. Consequently the Brownfield Process was explained step by step. Brownfield process guides systematically through module division and interface definition. It proposes making space reservations for all configurable elements which is a crucial part of creating working configurable product.

Existing design processes used in Konecranes have not been specifying steps for space reservation design. Therefore this thesis brought up findings from literature how the role of space reservations are managed during design and what space reservation models exist. Often studies regarding modular product development only recommend reserving enough installation space for all modules. However an example of space reservation model from MAN was introduced along some other methods.

In the beginning of this product development project it was thought the MAN-method would be the most suitable for this project. Nonetheless after deciding to standardize the most critical dimensions of the product under development, number of different possible configurations decreased and spatial checks can be done case by case with 3D-designing.

Based on learnings from the Brownfield Process this thesis suggested new steps for existing design process. Offer engineering should classify the product according to customer specification to a configurable, partly-configurable and one-of-a-kind product. Then configuration and spatial limitations can be reviewed and only detail engineering of new features will be left for the delivery project.

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